

**ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE**  
**ENGINEERING AND TECHNOLOGY**

**NUMERICAL INVESTIGATION OF HYDRODYNAMIC EFFECTS OF  
WAVES CAUSED BY LANDSLIDE IN DAM RESERVOIRS**



**Ph.D. THESIS**

**Vafa KHOOLOSI**

**Department of Civil Engineering**

**Hydraulics and Water Resources Engineering Program**

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**Vafa KHOOLOSI  
(501092506)**

**Department of Civil Engineering**

**Hydraulics and Water Resources Engineering Program**

**Thesis Advisor: Prof. Dr. Mehmet Sedat KABDAŞLI**

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**TOPRAK KAYMASI SONUCU OLUŞAN DALGALARIN BARAJ  
HAZNESİNDE OLUŞTURDUĞU HİDRODİNAMİK ETKİLERİN  
NÜMERİK OLARAK ARAŞTIRILMASI**

**DOKTORA TEZİ**

**Vafa KHOOLOSI  
(501092506)**

**İnşaat Mühendisliği Anabilim Dalı**

**Hidrolik ve Su Kaynakları Mühendisliği Programı**

**Tez Danışmanı: Prof. Dr. Mehmet Sedat KABDAŞLI**

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Vafa khoolosi, a Ph.D. student of İTÜ Graduate School of Science Engineering and Technology student ID 501092506, successfully defended the thesis entitled “NUMERICAL INVESTIGATION OF HYDRODYNAMIC EFFECTS OF WAVES CAUSED BY LANDSLIDE IN DAM RESERVOIRS”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

**Thesis Advisor :**                    **Prof. Dr. M. Sedat KABDAŞLI** .....  
ISTANBUL Technical University

**Jury Members :**                    **Prof. Dr. E. Beyhan YEĞEN** .....  
ISTANBUL Technical University

**Prof. Dr. Emel İRTEM** .....  
BALIKESİR University

**Doç. Dr. Mehmet ÖZGER** .....  
ISTANBUL Technical University

**Doç. Dr. Ahmet Doğan** .....  
Yildiz Technical University

**Date of Submission : 31 January 2017**

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*To my beloved wife and my parents,*



## FOREWORD

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January 2017

Vafa KHOOLOSI  
(Civil Engineer)



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## ABBREVIATIONS

|              |                                                         |
|--------------|---------------------------------------------------------|
| <b>2D</b>    | : 2-Direction                                           |
| <b>3D</b>    | : 3-Direction                                           |
| <b>AMR</b>   | : Adaptive Mesh Refining                                |
| <b>DNS</b>   | : Direct Numerical Simulations                          |
| <b>ENO</b>   | : Essentially Non-Oscillatory                           |
| <b>GOM</b>   | : Gulf of Mexico                                        |
| <b>ILU</b>   | : Incomplete lower-upper                                |
| <b>LES</b>   | : Large Eddy Simulation                                 |
| <b>MUMPS</b> | : Multi frontal Massively Parallel Sparse direct solver |
| <b>NOC</b>   | : Non-Oscillatory                                       |
| <b>NS</b>    | : Navier–Stokes                                         |
| <b>NSW</b>   | : Non-Linear Shallow Water                              |
| <b>PIV</b>   | : Particle Image Velocimetry                            |
| <b>PLIC</b>  | : Piecewise Linear Interface Construction               |
| <b>RANS</b>  | : Reynolds Averaged Navier–Stokes                       |
| <b>RNG</b>   | : Renormalization-Group                                 |
| <b>SPH</b>   | : Smoothed Particle Hydrodynamics                       |
| <b>TVD</b>   | : Total Variation Diminishing                           |
| <b>VOF</b>   | : Volume of Fluid                                       |
| <b>FAVOR</b> | : Fractional Area Volume Obstacle Representation        |



## SYMBOLS

|              |                                                       |
|--------------|-------------------------------------------------------|
| $\mu$        | : Dynamic viscosity                                   |
| $\Delta z$   | : Drop height                                         |
| $A$          | : Cross sectional area of blocks                      |
| $a_{c\ max}$ | : Maximum amplitude of impulse wave                   |
| $a_M$        | : Wave amplitude                                      |
| $b$          | : Slide width                                         |
| $c$          | : Wave celerity                                       |
| $d_g$        | : Grain diameter                                      |
| $E_{pot}$    | : Wave potential energy per unit width                |
| $E_s$        | : Slide energy per unit width                         |
| $E_w$        | : Wave energy per unit width                          |
| $E_w(0)$     | : Impulse wave energy at generation zone              |
| $f$          | : Coefficient of friction                             |
| $g$          | : Acceleration due to gravity (9.81m/s <sup>2</sup> ) |
| $h$          | : Water depth                                         |
| $h_0$        | : Still water depth                                   |
| $H_M$        | : Maximum wave height                                 |
| $k$          | : Friction coefficient                                |
| $l_s$        | : Slide length                                        |
| $m_s$        | : Mass of box                                         |
| $n$          | : Bulk slide porosity                                 |
| $\phi$       | : Slide front angle                                   |
| $r$          | : Radial distance                                     |
| $S$          | : Box thickness                                       |
| $T$          | : Indicating wave period                              |
| $t$          | : Time                                                |
| $T$          | : Wave period                                         |
| $t_{0s}$     | : Slide underwater travel time                        |
| $T_{max}$    | : Period of maximum wave                              |
| $t_s$        | : Slide thickness                                     |
| $v_s$        | : Slide impact velocity                               |
| $V_s$        | : Slide volume                                        |
| $w$          | : Slide width                                         |
| $x$          | : Stream wise coordinate                              |
| $\alpha$     | : Bed slope angle                                     |
| $\alpha$     | : Water-mudslide density ratio                        |
| $\gamma$     | : Wave propagation angle                              |
| $\rho_s$     | : Slide density                                       |
| $\rho_w$     | : Water density                                       |

|          |                                                      |
|----------|------------------------------------------------------|
| $\tau$   | : Fluid viscous stress tensor                        |
| $q$      | : Pressure                                           |
| $\mu_1$  | : Water Viscosity                                    |
| $\rho_1$ | : Density of the water                               |
| $\eta_1$ | : Water-surface elevation measured from the datum    |
| $\mu_2$  | : Mudslide Viscosity                                 |
| $\rho_2$ | : Density of the mudslide                            |
| $\eta_2$ | : Mudslide-surface elevation measured from the datum |



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# **NUMERICAL INVESTIGATION OF HYDRODYNAMIC EFFECTS OF WAVES CAUSED BY LANDSLIDE IN DAM RESERVOIRS**

## **SUMMARY**

The water wave generation by a freely falling rigid body is examined in this thesis. Landslides on the margins of dam reservoirs may generate large waves that can produce flooding over the banks or overtopping the dam crest. In the present investigation, landslide generated waves are studied using a numerical model based on Navier-Stokes equations. Impulse wave amplitude, period, energy are studied in this work. The effects of bed slope angle on energy conversion from slide into wave are also investigated, and the numerical model we used in this study is the full three dimensional commercial code FLOW-3D.

The purpose of this research is to fill in missing data regarding water waves generated by landslides through numerical modeling to create a three dimensional representation of water waves generated by landslide behavior. This information could eventually be utilized to transform assessment and mitigation of the tsunami threat. The data collected could in turn drastically reduce the resulting loss of life from a landslide impact.

Because of complication of physics of landslide generated impulse waves, still not all influential parameters are fully recognized. In the present work deals with the complex problem of numerical modeling landslides generated waves. Despite the huge amount of work on the subject, there are many aspects that are not yet completely solved, for example the development of an early warning system capable to alert people in time. The complexity of the problem lies on the mechanism and the physics of the phenomenon that is fully three-dimensional in the near field. Moreover, the dynamical description of the landslide is very complicated to simulate as well as the interaction with the water. The aim of this work is to implement and apply a numerical model able to provide detailed simulations of water waves generated by landslides. The capability of this model to represent the dynamic of the landslide introducing a rheological model is also investigated.

The purpose of this thesis is to model, analyze and study of the wave behavior generated by landslides into the dam reservoir. For this reason, modeling is first implemented on small dimensions of channel to study the consequences of slide shapes and their rigidity or granularity in order to determine whether the physical shape of the slides can impact the generated waves or not.

Also, whether the rigidity or granularity of slides can leave any influence on water run-up in dams. After this modeling, all these findings are carried out in the real case of the Maku Dam so that the wave behavior is fully studied to prevent the dam failures and subsequent damages caused by water run-up.

Thus, only the first simulations are conducted considering the landslide as a rigid body and using Smoothed Particle Hydrodynamics (SPH) numerical model, after that

SPH is used to simulate the landslide as a deformable body, testing and applying a particular rheological model. Finally 3D simulation of deformable landslides falling into the water are performed.

The choice of this particular fully lagrangian model is due to the possibility of simulating generation, propagation and run-up of the impulse waves, without any particular constraint on the free surface.

By understanding the wave behavior and the variations of velocity vectors, water run-up, dam failure, flooding and the sinking of the downstream lands can be anticipated.

Results of the Navier-Stokes model show that waves generated are highly dependent upon the details of slide mechanism and kinematics. Numerical solutions for the velocity fields, pressure distributions, and turbulence intensities in the vicinity of the falling rigid body are also presented. Results show that the general pattern of wave in all cases is the same but the amplitude and period are different.

Data analysis shows that the maximum wave crest amplitude in subaerial induced waves is strongly affected by bed slope angle, landslide impact velocity, thickness, kinematics and deformation and by landslide shape. The effects of the main parameters such as, impact velocity, slide geometry, shape and deformation on the impulse wave characteristics have been inspected. Moreover, Laboratory investigations have been performed on the impulsive waves caused by subaerial and submarine landslide. Numerical analyses were performed to simulate the wave generation due to subaerial and submarine landslide.

Different types of landslide geometries were used to analyze the flow field. Simulated results show complex flow patterns in the lake in terms of velocity field, and free surface profiles. Numerical results of wave amplitudes and velocity magnitudes for circular, rectangular and triangular landslide geometries are applied to the sliding materials are computed, which are used by geotechnical engineers to study the stabilization of the slope.

The extended model is applied for simulating real case, the Maku Dam reservoirs located in the northwestern of Iran. The generated wave heights, wave run-up, maximum wave height have been evaluated for each case. The maximum wave heights is 3.6 m.

The results of numerical analyses demonstrate that the general pattern of wave in all cases is the same but the amplitude and period are different. The numerical analyses show that the maximum wave crest amplitude in subaerial induced waves was strongly affected by deformation and by landslide shape. Slide deformation made a maximum reduction on wave crest amplitude down to 34% and a maximum increase up to 30% on period, although no strong changes in general pattern of subaerial impulse wave features. Slide shape did not strongly affect the general feature of impulse wave and at most the amplitude and period were changed less than 10%. Finally, the results of the Navier-Stokes model show that waves generated were highly dependent upon the details of slide mechanism and kinematics.

The model extended for simulating impulsive waves was caused by subaerial landslides entering a water body. A set of three-dimensional experimental data was used to validate the extended model. The time phase differences and the estimation

error of the wave amplitudes were less than 14% and 5%, respectively. The estimation error of the wave amplitude for the majority of the simulated experiments is less than 1%. Therefore, the extended model is able to simulate subaerial-landslide-generated waves with a degree of accuracy similar to that observed for the simulated submarine-landslide-generated waves in generation and propagation stages.

The extended model was applied for simulating real case, the Maku Dam reservoirs located in the northwestern of Iran. The generated wave heights, wave run-up, maximum wave height were evaluated for each case.

Keywords: Dam reservoir, subaerial and submerge landslide, impulsive water wave, numerical model.





# **TOPRAK KAYMASI SONUCU OLUŞAN DALGALARIN BARAJ HAZNESİNDE OLUŞTURDUĞU HIDRODİNAMİK ETKİLERİN NÜMERİK OLARAK ARAŞTIRILMASI**

## **ÖZET**

Bu tez çalışmasında serbest düşen bir rijit cisimin oluşturduğu su dalgası incelenmiştir. Baraj gölü kenarlarındaki heyelanlar, taşkınlara neden olabilir veya baraj tepesini aşacak kadar büyük dalgalar üretebilir. Mevcut araştırmada heyelanla oluşturulan dalgalar Navier-Stokes denklemlerine dayalı sayısal bir model kullanılarak incelenmiştir. Bu çalışmada impuls dalga genliği, periyot, enerji araştırılmıştır. Bu çalışmada kullanılan sayısal model FLOW-3D üç boyutlu kodudur.

Bu araştırmanın amacı, heyelan davranışlarından kaynaklanan su dalgalarının üç boyutlu bir temsili oluşturmak için sayısal modelleme yoluyla heyelanların oluşturduğu su dalgaları ile ilgili eksik çalışmaları doldurmaktır. Bu bilgi tsunami tehdidinin değerlendirilmesi ve hafifletilmesi için kullanılabilir. Toplanan veriler sonuç olarak heyelan etkisinden doğan yaşam kaybını önemli ölçüde azaltabilir.

Heyelanın ürettiği dürtü dalgalarının fiziğinin karmaşıkından dolayı hala tüm etkili parametreler tamamen tanınmamaktadır. Mevcut çalışmada sayısal modellemenin karmaşık problemi ile ilgili araştırmalara göre heyelanlar dalgalar üretmektedir. Konuyla ilgili büyük miktarda çalışmaya rağmen, insanları zamanında uyarabilecek bir erken uyarı sisteminin geliştirilmesi gibi, henüz tam olarak çözülmeyen pek çok sorun vardır. Sorunun karmaşıklığı, yakın alan içerisinde tamamen üç boyutlu olgunun mekanizması ve fiziği üzerine kuruludur. Dahası, heyelanın dinamik açıklaması, su ile etkileşimin yanı sıra simüle olması da oldukça karmaşıktır. Bu çalışmanın amacı heyelanların oluşturduğu su dalgalarının detaylı simülasyonlarını sağlayacak sayısal bir model uygulamak ve uygulamaktır. Bu modelin reolojik bir modeli tanıtan heyelan dinamiğini temsil etme kabiliyeti de araştırılmıştır.

Bu tezin amacı, heyelanlar tarafından oluşturulan dalga davranışını baraj gölünde modellemek, analiz etmek ve incelemektir. Bu nedenle, modelleme ilk önce cismin şekillerinin sonuçlarını incelemek için küçük boyutlu kanallar üzerine uygulanır ve cisimlerin fiziksel şeklinin oluşturulan dalgaları etkileyip etkilemeyeceğini belirlemek için katılık veya muğlaklıkları belirlenir.

Ayrıca, kütlelerin sertliği veya ayrıntı düzeyi, barajlarda suyun yükselmesi üzerinde herhangi bir etkisi bırakıp bırakmaması araştırılmıştır. Bu modellemeyi takip eden, tüm bu bulgular Maku Barajı'nın gerçek durumu üzerinde yürütülmüş, böylece barajın bozulmasını ve daha sonra meydana gelen suyun yükselmesinin önlenmesi için dalga davranışları tam olarak incelenmiştir.

Bu çalışma tamamen Lagrange modelin seçimi, serbest yüzey üzerinde belirli herhangi bir kısıtlama olmaksızın, dürtü dalgalarının oluşturulması, yayılması ve çalıştırılmasını taklit etme olasılığına bağlıdır.

Dalga davranışını ve hız vektörlerinin çeşitlerini anlamak suretiyle, suyun yükselmesi, barajın çökmesi, taşkın olması ve aşağı doğru topraklarda batma öngörülebilir.

Navier-Stokes modelinin sonuçları, oluşturulan dalgaların kayma mekanizması ve kinematik detaylarına büyük ölçüde bağlı olduğunu göstermektedir. Düşen rijit cisim çevresinde hız alanları, basınç dağılımları ve türbülans yoğunlukları için sayısal çözümler de sunulmuştur. Sonuçlar, her durumda dalganın genel modelinin aynı olduğunu, ancak amplitüd ve periyodun farklı olduğunu göstermektedir.

Veri analizi karasal kaynaklı dalgalar halinde maksimum dalga tepesi genliği kuvvetle yatak eğim açısı, heyelan darbe hızı, kalınlık, kinematiği ve deformasyon ile ve heyelan şekli etkilendiğini göstermektedir. Çarpma hızı, kütle geometrisi, şekli ve deformasyonu gibi temel parametrelerin darbe dalgası özellikleri üzerindeki etkileri incelenmiştir. Denizüstü ve denizaltı toprak kaymalarının neden olduğu dürtüsel dalgalar üzerine laboratuvar incelemeleri yapılmıştır (Ataie-Ashtiani, 2008; Najafi-Jilani, 2008). Denizüstü ve denizaltı heyelanlarından dolayı dalga üretimini simüle etmek için sayısal analizler yapılmıştır.

Akış alanını analiz etmek için çeşitli heyelan geometrileri kullanılmıştır. Simüle edilmiş sonuçlar, hız sahası ve serbest yüzey profilleri açısından göldeki karmaşık akış modellerini göstermektedir.

İRAN'ın kuzeybatısındaki Maku Barajı nümerik modeli uygulanmaktadır. Oluşan dalga yükseklikleri, dalga yükselmesi, baraj kretinin üstündeki maksimum dalga yüksekliği ve baraj yükselme hacmi değerlendirilmiştir. Baraj gövdesine yakın maksimum dalga yüksekliği 3.6 m'dir.

Sayısal analiz sonuçları, tüm durumlarda dalganın genel modelinin aynı olduğunu, ancak genlik ve periyodun farklı olduğunu göstermektedir. Sayısal analizler karasal kaynaklı dalgalar halinde maksimum dalga tepesi genliği güçlü deformasyon ile ve heyelan şekli etkilendiğini göstermektedir. Kütle deformasyon, aşağı% 35 dalga kret genliği üzerinde maksimum azalma ve dönemine göre% 30'a kadar maksimum artış yapılmış karasal darbe dalga özelliklerinin genel desen hiçbir güçlü değişiklikler olmasına rağmen. Kütlenin şekli kuvvetle dalga genel özelliği etkilemektedir ve en genlik ve periyot% 10'dan az değişmektedir. Son olarak, Navier-Stokes modelinin sonuçları, oluşturulan dalgaların kayma mekanizmasına ve kinematik detaylarına oldukça bağımlı olduğunu göstermektedir.

Dürtüsel dalgaları taklit etmek için genişletilen model, bir su kütesine giren Denizüstü heyelan kaynaklıdır. Genişletilmiş modeli doğrulamak için bir dizi üç boyutlu deneysel veri kullanılmıştır. Zaman faz farkları ve dalga amplitütlerinin tahmin hatası sırasıyla % 15 ve % 5'in altındadır. Simüle deneylerin çoğunluğu için dalga genliğinin tahmin hatası % 1'den düşüktür. Bu nedenle, genişletilmiş model, üretim ve yayılım aşamalarında simüle edilen deniz altı heyelanı tarafından üretilen dalgalar için gözlemlenenlere benzer bir doğruluk derecesinde, hava-altı heyelanla oluşturulan dalgaları simüle edebilir.

İRAN'ın kuzeybatısındaki Maku Barajı rezervuarlarının gerçek durumunun taklit edilmesi için genişletilmiş model uygulanmıştır. Oluşan dalga yükseklikleri, dalga yükselmesi, baraj kretinin üstündeki maksimum dalga yüksekliği ve baraj tepe hacmi her vaka için değerlendirilmektedir.

Maku Barajının ilk simülasyonu için baraj gövdesine yakın maksimum dalga yüksekliği 3.6 m dir. Bu nedenle, en iyi durumda, aşırı yükselme olmamaktadır. En kötü koşullarda (yağışlı mevsimlerde), aşırı ısınma olmaz.

Anahtar Kelimeler: Baraj Gölü, Denizüstü ve Denizaltı Heyelan, Su Dalgası, Sayısal Model.





## 1. INTRODUCTION

Dams are usually built in valleys where active erosion is present, and some are in active earthquake areas. Therefore, reservoirs can be vulnerable to landslides activated by earthquakes or by heavy rains or snows and they could generate large waves that can produce flooding over banks or overtopping the dam crest (Heller, 2007).

As dam safety is a significant issue in dam engineering, studies of these natural accidents and their consequences must be considered in the project phase of a dam and regular operation stages, especially when the construction site is placed in a high risk seismic activity zone, or when the geological study indicates the existence of a potential landslide area. The study of these phenomena, including slope failures, the generation of waves and their impacts on the dam should be integrated (Heller, 2007; Imamura, 1969).

Studies of natural landslides that happen in dam reservoirs show that they were induced mainly by earthquakes or heavy rains or snows. Several ways of landslides classification could be used: sliding mass can be initially non submerged, partially or completely submerged; the material can be more or less compact or dense, granular or fine (rock and soil, snow); the sliding mass volume could be variable from small to great volumes; sliding mass velocity at the moment of the impact is dependent on the balance of forces/moments, which are influenced by the dynamic properties of soil, by the soil brittleness and by topographic effects; the size or volume, and the reservoir depth (Imamura, 1969).

Landslides are the second most common triggers for causing tsunamis after earthquakes. Compared to seismic tsunamis landslides generated tsunamis may be larger but due to the fast decay these waves, are usually considered as a local phenomenon and not a global incident. Generation mechanism of landslide induced tsunamis depends on initial position of the landslide relative to still water level (Figure 1.1). From this point of view, landslides are classified as submarine (underwater), partially submerged or subaerial landslides. Subaerial landslides often generate much larger waves compare to the other two (Moalemi, 2010).

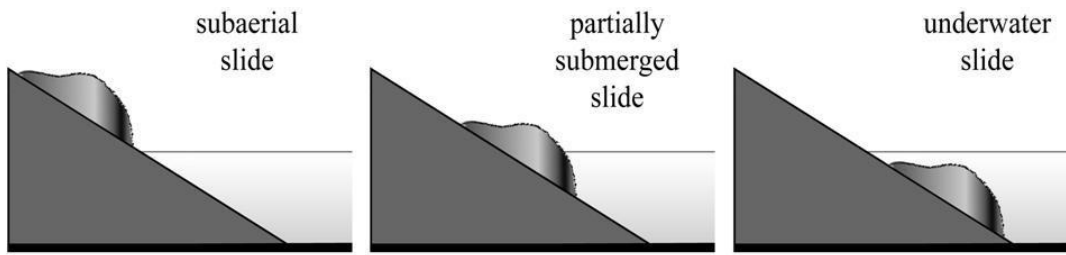


**Figure 1.1:** Impulse wave generation categories (Moalemi, 2010)

One of the most destructive landslide generated tsunamis was observed in 1959 in Lituya Bay, Alaska, when a subaerial landslide of  $31 \times 10^3 \text{ m}^3$  volume, which was triggered by an earthquake, slides into the bay and lead to a tsunami. The wave with the highest ever recorded wave run-up of 254 meters on the opposite shore of the bay propagated towards Pacific Ocean (Moalemi, 2010).

Another lethal instance of landslide generated tsunamis took place in 1963 in northern Italy. A landslide of  $270 \times 10^3 \text{ m}^3$  volume impacted the water impounded by Vajont dam, which was a newly constructed concrete arch dam, and the overtopping of the 300 m height impulse wave destroyed the town of Longarone, located behind the dam (the overtopping was 70 m).

Although not all impulse waves caused by landslides are as destructive as the mentioned cases but where ever tsunamis occur, the waves propagate at high speed to a far distance from the slide impact point with little energy dissipation (compared to e.g. wind waves) hence this can lead to devastation in coastal regions, shoreline damages, dam over topping in case of artificial reservoirs, downstream flooding and generally financial losses and even human perishes (Moalemi, 2010).

Certain environments such as mountainous regions are more vulnerable to landslide generated tsunamis because of their steep valley sides and unstable and steep slopes (e.g. Alpine regions).

A high risk environments hazard forecasting is essential but at present in order to prevent major casualties and reduce consequences of such catastrophes, mainly passive methods can be applied. These strategies are such as evacuation, freeboard control, water level draw-down in artificial reservoirs and blasting of possible slides. To perform any of the aforementioned operations precise information on landslides physics and wave features is necessary. Also in order to build and maintain coastal

and hydraulic structures (e.g. dams) effects of these waves on structures or the shoreline should be investigated. To calculate these forces wave height  $H$ , wave amplitude  $a$ , and wave length  $L$  at specific locations of the reservoir are required (Moalemi, 2010).

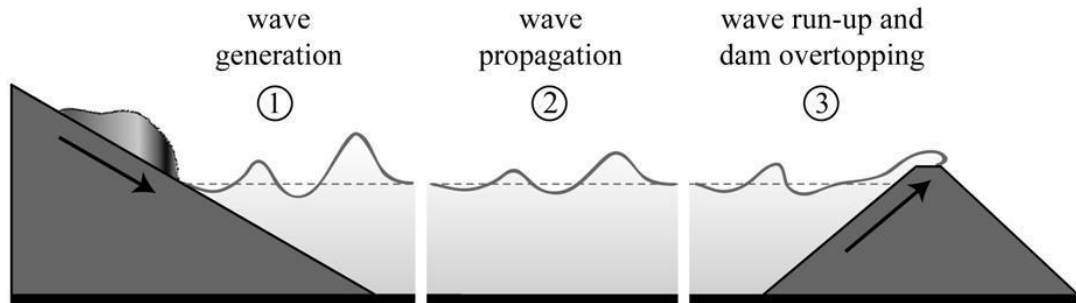


**Figure 1.2 :** The three phases of an impulse wave above a horizontal reservoir bed (Moalemi, 2010)

Figure 1.2 shows the three phases of development of an impulse wave above a horizontal reservoir bed: (1) slide impact with the wave generation, this zone is referred to as wave generation zone hereafter, (2) wave propagation with the wave transformation (namely wave propagation zone) and (3) impact and run-up of the impulse wave with the load transfer to a dam and overtopping of the dam.

Several parameters are involved in generation and propagation of landslide induced tsunamis. These waves are highly non-linear and therefore the identification of each parameter and predicting features of the wave is a complicated process. Types and features of the landslide and topology and geometry of the reservoir in which impulse wave occurs affect the characteristics of the waves.

Features of tsunami type waves can be predicted by applying five different strategies: specific prototype studies, numerical simulations, prediction based on field data, analytical calculations, and general model studies.

Various physical and numerical simulations have been performed since the mid nineteenth century started from the study of Russell (1837) using a block model in a prismatic wave channel in order to examine governing parameters of generating impulse waves and also several empirical equations have been developed with Heller (2008).

Shape and dimensions of the basin highly affect impulse wave propagation mechanism and affects waves parameters such as wave height, wave length, wave period etc. This was denoted by Camfield (1980) and emphasized by Heller et al. (2005) amongst others.

Studies on landslide generated impulse waves have mostly been conducted in either wave channels (2D), where the waves propagate along the channel axis and measurements are in two dimensions, or in wave basins (3D), in which waves can propagate radically freely and measurements are conducted in three dimensions. However in reality geometries often remarkably differ from these two extreme cases.

Studying effects of geometry on landslide generated impulse waves have been subject of some numerical investigations yet it is not completely understand how different geometries may lead to different behaviors of impulse waves.

In general, geometries can just be estimated by using formulas derived from studies on the two extreme geometries (2D and 3D) (Ataie-Ashtiani, 2008; Najafi-Jilani, 2008).

### **1.1 Aims and Targets of this Thesis**

The aim of this thesis is to fill in missing data regarding water waves generated by landslides through numerical modeling to create a three dimensional representation of water waves generated by landslide behavior. This information could eventually be utilized to alter assessment and mitigation of the tsunami threat. The data collected could in turn drastically reduce the resulting loss of life from a landslide impact.

Because of complication of physics of landslide generated impulse waves, still not all influential parameters are fully recognized. The present work deals with the complex problem of numerical modeling landslides generated waves. Despite the huge amount of work on the subject, there are many aspects that are not yet completely solved, for example the development of an early warning system capable to alert people in time. The complexity of the problem lies on the mechanism and the physics of the phenomenon that is fully three dimensional in the near field. In addition, the dynamical description of the landslide is very complicated to simulate as well as the interaction with the water. The goal of this work is to implement and apply a numerical model able to provide detailed simulations of water waves generated by

landslides. The capability of this model to represent the dynamic of the landslide introducing a rheological model is also investigated.

The purpose of this thesis is to model, analyze and study of the wave behavior generated by landslides into the dam reservoir. For this reason, modeling is first implemented on small dimensions of channel to study the consequences of slide shapes and their rigidity or granularity in order to determine whether the physical shape of the slides can impact the generated waves or not.

Also the rigidity or granularity of slides can leave any influence on water run-up in dams. After this modeling, all these findings are carried out on the real case of the Maku Dam so that the wave behavior is fully studied to prevent the dam failures and subsequent damages caused by water run-up.

Thus, only the first simulations are conducted considering the landslide as a rigid body and using Smoothed Particle Hydrodynamics (SPH) numerical model, after that SPH is used to simulate the landslide as a deformable body, testing and applying a particular rheological model. Finally 3D simulation of deformable landslides falling into the water is performed.

The choice of this particular fully Lagrangian model is due to the possibility of simulating generation, propagation and run-up of the impulse waves, without any particular constraint on the free surface.

By understanding the wave behavior and the variations of velocity vectors, water run-up, dam failure, flooding and the sinking of the downstream lands can be anticipated.



## 2. LITERATURE REVIEW

The term landslide is generally used to describe the movement of a mass of rock, debris or earth down a slope. In the English literature, the most widely used classification of landslides is given by Varnes (1978).

The landslide can be classified and described by two nouns, the first noun describes the landslide material and the second noun describes the type of movement. The landslide material is divided into two classes: rock and engineering soils; soils are further divided into debris and earth (Mohammed, 2012; Fritz, 2012).

The types of movement are divided into five groups: falls, topples, slides, spreads and flows. The classification of slope movement by Varnes (1978) is shown in Table 2.1.

**Table 2.1** : Landslide classification after Varnes (1978)

| MOVEMENT TYPE   |               | TYPE OF MATERIAL                             |                    |                   |
|-----------------|---------------|----------------------------------------------|--------------------|-------------------|
|                 |               | BEDROCK                                      | ENGINEERING SOILS  |                   |
|                 |               |                                              | COARSE             | FINE              |
| Falls           |               | Rock fall                                    | Debris fall        | Earth fall        |
| Topples         |               | Rock topple                                  | Debris topple      | Earth topple      |
| Slides          | rotational    | Rock slump                                   | Debris slump       | Earth slump       |
|                 | translational | Rock block slide                             | Debris block slide | Earth block slide |
|                 |               | Rock slide                                   | Debris slide       | Earth slide       |
| Lateral spreads |               | Rock spread                                  | Debris spread      | Earth spread      |
| Flows           |               | Rock flow                                    | Debris flow        | Earth flow        |
| Complex         |               | Combination of two or more types of movement |                    |                   |

### 2.1 Landslides

There is a complete gradation from debris slides to debris flows depending on the water content, mobility and the character of the movement. Radbruch-Hall (1978) proposed the terms to describe the water content of landslide materials made by simple observations of the displaced material. Varnes (1978) presented the modified terms of Radbruch-Hall (1978) as follows:

- Dry: no visible moisture.

- Moist: contains some water but no free water; the material may behave as a plastic solid but does not flow.
- Wet: contains enough water to behave in parts as a liquid, has water flowing from it or supports significant bodies of standing water.
- Very wet: contains enough water to flow as a liquid under low gradients.

As the slide movement becomes more rapid, the transition from debris slide to debris avalanche becomes important regarding the generation of tsunamis. The term debris avalanche is used in general to describe very rapid and extremely rapid debris flows of dry or largely unsaturated granulates (Cruden, 1978; Varnes, 1978).

Two limiting cases of landslide avalanche are termed flow avalanche and powder avalanche Hutter (1996) depending on the role of the interstitial fluid. Flow avalanche is a dense gravity driven laminar flow where the solid particles dominate the flow dynamics and the behavior of the interstitial fluid is negligible (Harbitz, 1992).

Powder avalanche is the turbulent flow of air borne particles in which the fluid phase dominates the flow dynamics and the particle flow dynamics are of less significance. Density and turbidity currents such as dust clouds in deserts, in pyroclastic volcanic eruptions, in submarine slides and in snow and ice avalanches are the typical flows belonging to powder avalanche. In this section, the development of the granular landslide physics, their governing dynamical equations and the numerical solutions to the dynamic problem are reviewed. In the end, comparative studies between experimental data and numerical solutions are summarized. The focus is on the dynamics of granular landslides without delving into the source or cause of the landslides (Mohammed, 2012; Fritz, 2012).

## **2.2 Landslide Dynamics**

Heim (1932), found that the slope of the energy line for landslides is approximately the same as the coefficient of friction for sliding masses. This friction coefficient was referred as the equivalent coefficient of friction by Shreve (1968). The equivalent coefficient of friction was found to depend on the size of a landslide unlike the coefficient of friction which is a material constant. A log-log plot of the equivalent coefficient of friction as a function of the landslide volume is shown in Figure 2.1.

The plot includes subaerial dry-rock avalanches of non volcanic origin, submarine landslides and Martian landslides (McEven, 1989). All of the above cases indicate decay in the equivalent friction of coefficient with increasing landslide volume. The correlation for subaerial landslides between the coefficient of friction and the landslide volume  $V_s$  in  $m^3$  is given as (McEven, 1989)

$$\text{Log } f = 0.15666 \log V_s + 0.62419 \quad (2.1)$$

with a correlation coefficient of 0.82. The relation in Equation 2.1 also depends on the type of landslide material. For example, quick clays have friction coefficients at the lower end of friction coefficients observed for submarine landslides (Edgers and Karlsrud, 1982).

### 2.3 Granular landslide experiments

Experimental studies on granular avalanches range from the initial one-dimensional study of mass flow down rough, inclined surfaces to the unconfined three-dimensional mass flow over complex topographies. Selected 1D experimental setups are shown in Figure 2.1.

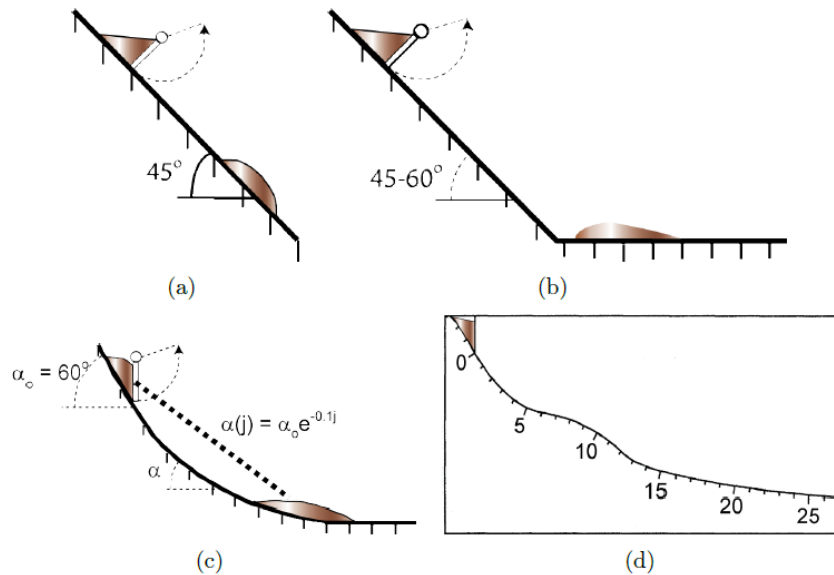


**Figure 2.1 :** Experimental setup for one-dimensional granular mass flow: (a) Experimental setup by (Huber,1980); (b) Experimental setup by Pluss (1987); (c) Experimental setup by Koch (1989) and (d) Experimental setup by Greve and Hutter (1993).

These studies were later extended to include lateral granular spreading and fully three-dimensional granular landslides as shown in Figures 2.2(a) and 2.2(b). The experimental studies were also conducted to study confined flows in inclined rectangular channels as shown in Figure 2.2(c). Recently, more complex scenarios involving granular mass flows in channels with twisting have been physically modeled as shown in Figure 2.2(d) (Mohammed, 2012; Fritz, 2012).

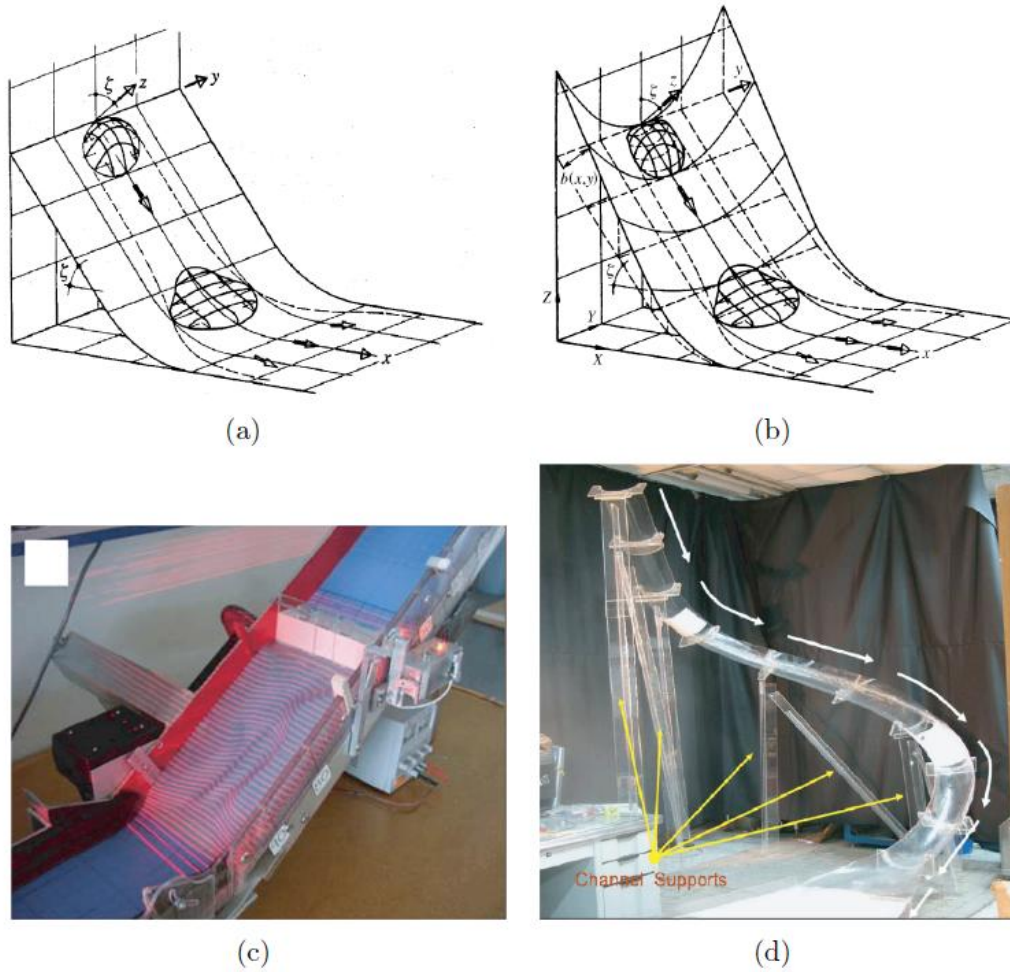


**Figure 2.2 :** Granular flows on inclined surfaces: (a) Experimental setup by Koch et al. (1994), (b) by Gray et al. (1999), (c) (Iverson et al., 2004) and (Pudasaini et al., 2008)

## 2.4 Granular landslide models

The flow of granular materials can be applied to study geophysical flows such as landslides, rock, ice and snow avalanches and pyroclastic flows (Hutter, 1994; Rajagopal, 1994). Kinetic theory and molecular dynamics models were developed to describe the rheology of granular materials (Jenkins 1983; Savage, 1983; Haff, 1983; Lun et al.;1986), (Jenkins and Richman, 1985), (Campbell and Brennen, 1985),

(Campbell and Gong, 1986), (Walton and Braun, 1986)). For example, in the Jenkins-Savage model (Jenkins and Savage, 1983) the granular material is assumed to be composed of identical spheres of constant diameter which under collisions may transmit linear momentum but not angular momentum. The collision of the particles is assumed to be inelastic. Ahmadi (1983) and Shahinpoor (1983) extended the dilute gas model where the assumption is that as particles collide, a fraction of the particles after the collisions behave according to the Maxwell-Boltzmann distribution. This fraction is adjustable in the model. The model implicitly assumes that the interstitial space between the granular material is filled with gas and thus a drag due to flow of a fluid past a solid is introduced as a mechanism for the interaction of the interstitial gas with the granular particles. The model of Massoudi (1991) and Boyle (1991) adapts the Enskog dense gas theory, which allows for gradients in the volume fraction and predicts normal stress differences in simple shear flows of the granular materials. Oppenheim (1990) and McBride, (1990) and Oppenheim (1991) used methods of statistical mechanics to model the granular dynamics. The model assumes that spherical particles are inelastic and have many degrees of freedom which are essentially at equilibrium close to zero Kelvin except for very short times. However, the requirement that the particles are essentially in equilibrium close to zero degrees Kelvin is a very stringent assumption which might make the theory inapplicable to granular materials (Ataie-Ashtiani 2011; Yavari, 2011).

Other models describing granular landslides assume them as single mass points sliding along a prescribed geometry of a mountain side (Perl et al.,1980) or hydraulictype models (Voellmy, 1955; Salm, 1966). In these models, the point masses are exposed to resistive forces that can be represented by the sum of two contributions, a dry Coulomb type and a turbulent friction type. These contributions involve a phenomenological parameter that can be adjusted according to the terrain and landslide considered. However, these assumptions limit the calculation of the temporal evolution of the geometry of the moving landslide. Continuum models describe landslides as linear Newtonian fluids (Brugnot, 1979; Dent and Lang, 1980) leading to Navier-Stokes equations and thus describe the slide motion (Mohammed, 2012; Fritz, 2012).

The models based on kinetic theories and molecular dynamics were found to be difficult to solve in temporally developing gravity driven flows. A simpler hydraulic

model for granular avalanche and landslide dynamics was developed by Savage (1989), Hutter, (1989), Savage and Hutter (1991) analogous to fluid flow models. Field observations and experimental studies have shown that the granular landslides behave in a near fluid-like manner and are found to deposit in a very long and thin layer. This general behavior of granular avalanches coupled with certain simplified assumptions makes it possible to model granular mass flows similar to fluid flows. The assumptions that make this model possible and true to the granular physics are incompressibility or density preserving, shallow avalanche piles and topography curvature, uniform velocity profile across the avalanche depth, Coulomb-type sliding on the bed and Mohr-Coulomb frictional behavior in the interior of the granular mass.

Field observations and experimental study have shown minimal density changes in granular avalanches and were observed to move as a thin, long and wide mass with small aspect ratios. It was also suggested by Melosh (1986) that the sliding occurs on a thin basal layer with high shear rates where nearly all shearing takes place. Hence, the depth changes due to dilation are small and the mass flow behaves like a Boussinesq medium without any buoyancy forces. The thin basal layer also shows that the depth-averaged stream wise velocity is close to the actual velocity everywhere across the depth except in the basal layer. The rheology of the granular material is described by treating it as an incompressible Coulomb continuum. A basal friction law is imposed to allow for sliding on the inclined bed. This is a dry Coulomb-like friction law that relates the shear traction to the normal pressure at the base and involves the friction angle between the gravel and the rough bed.

These assumptions lead to a dynamical fluid flow-like model which is derived from the conservation laws of mass and momentum. In general, the model consists of nonlinear partial differential equations for the landslide thickness and two depth averaged velocity components. The last two equations for the depth averaged velocities can either be expressed in terms of the stream wise and the transverse velocity components or in terms of the two topography parallel velocity components. In any case, these depth-averaged velocity components define the landslide propagation and deformation along the slide slope topography (Mohammed, 2012; Fritz, 2012).

The early numerical solutions of the granular avalanche model were solved using Lagrangian finite-difference schemes with central difference approximation and leap frog method in time by Savage and Hutter. The Lagrangian scheme required the addition of an explicit numerical diffusion when the gradients of the avalanche thickness and the velocities were large. These methods were also unable to capture the shocks and may have smoothed out the shocks due to the nature of the finite difference based schemes. A two-dimensional Eulerian shock capturing scheme and a one-dimensional front tracking method was developed and employed by Tai (2000) and Tai et al. (2002).

Wang et al. (2004) used a high resolution non-oscillatory (NOC) scheme and made a comparison for various cell reconstruction techniques. These techniques were four different second order total variation diminishing (TVD) limiters and a third order essentially non-oscillatory (ENO) cell reconstruction scheme. Of the numerical methods above, the NOC scheme with the minmod TVD limiter showed best performance for granular flows down curved chutes merging into a horizontal plane (Wang et al., 2004; Hutter et al., 2005). Apart from these numerical models, Denlinger and Iverson (2004), Iverson et al.(2004) and Pudasani et al. (2008) used shock capturing techniques to solve the extended model equations on a regular Cartesian grid. Pitman et al. (2003) computed flow along a two-dimensional surface using a parallel, adaptive grid, shock capturing method to solve the avalanche model. The model was solved on a cartesian grid which was developed from digital elevation topographic data using a parallel finite volume Godunov solver. A Lagrangian-Eulerian, finite-volume method with unstructured boundary fitted, moving, adaptive grid following the free boundary was developed by Koschdon and Schafer (2003). While the flow solver in this case consists of a Godunov-type solver, Vollmoller (2004) used a wave propagation method on an unstructured finite volume grid.

The initial comparisons between numerical solutions of the Savage-Hutter granular avalanche model and experimental data were made by Savage and Hutter (1989). The experimental data were taken from the laboratory experiments of Huber (1980) on impulse wave generation by granular landslides. The measurements made relating to the granular mass motion released from rest were compared with the motion of the slide front, tail and maximum thickness from the numerical solution. The slide

motion in both the cases is shown in Figure 2.3. The gravel mass was found to spread quickly and approaches a long and thin layer with depth of one or two particles within one second. Figure 2.3 inset shows the comparison of the dimensionless velocity of the slide front, middle and tail between the experiments of Huber (1980) and the numerical solution of Savage and Hutter (1989).

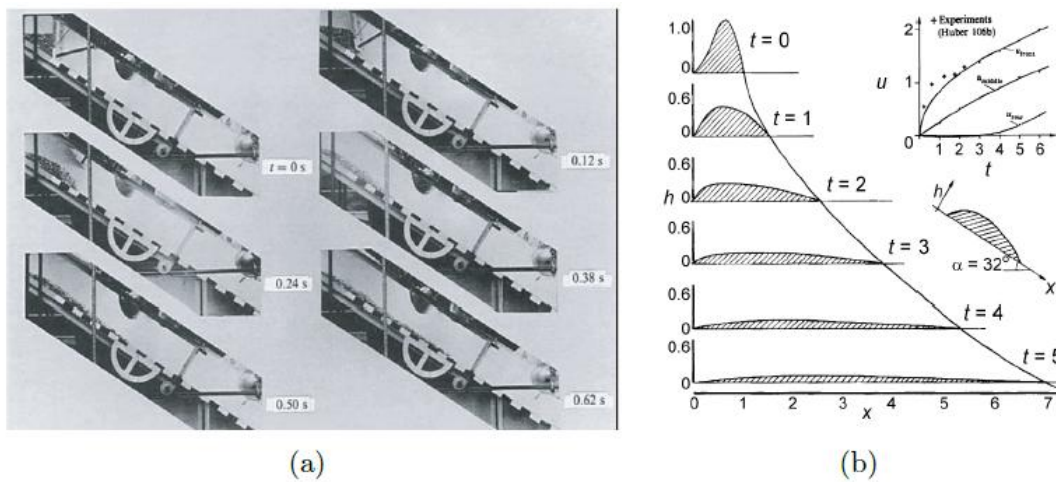


**Figure 2.3 :** Granular slide motion comparison between experiment and numerical model: (a) slide motion from rest on an inclined surface (Huber, 1980) and (b) numerical slide motion by Savage and Hutter (1989)

Comparative studies between physical models and numerical simulations of the Savage-Hutter avalanche model can be found in Hutter and Koch (1991). The scenarios include one-dimensional flow on rough straight and curved inclines, fully three-dimensional unconfined lateral spreading flow along straight and curved inclines, confined flows in rectangular channels with straight surface and complex topographies, confined flows in twisted and curved channels and straight and deflected runout flows. The observations made from the experimental and numerical studies can be summarized as follows.

- The model does not resolve small granular piles because of the extensively bouncing particles in the pile.
- The comparison fails in some cases due to numerical instability or coarse division of the granular mass into cells.
- The comparison fails in terms of the slide tail motion probably due to the simplicity of the Coulomb friction law, which in reality can be quite complex.

- Since the friction angle can change from a static to a dynamic state in real flows, a constant friction factor angle can under predict dilation. This can be resolved by having different friction angles for the slide tail and the rest of the slide body.
- Complex topographies can confine and channelize granular flows.
- In three-dimensional slide flows, strong Coulomb shear stresses develop normal to the basal surface. These stresses result in strong energy dissipation in case of obstructions. Thus, the numerical models should include multi-dimensional momentum transport and Coulomb friction to account for these stresses and energy dissipation.

In the experiment, the rounded gravel constituting the landslide mass was released from rest which results in an instant collapse of the slide mass. This leads to a large spread of the granular mass and while the first grain is at the bottom of the incline, the last grain is still at the initial rest position. However, in nature most landslides usually originate as a sliding block which make a transition from block slide to a debris avalanche.

Landslide generated waves are classified as nonlinear gravity water waves. Occurrence of these impulse waves can lead to some of the most destructive natural catastrophes. In order to decrease the amount of damage from this phenomenon on the structures and properties and the number of human losses the characteristics of these waves should be investigated. Therefore studying the behaviour of these impulse waves and their effects on the structures and shorelines are of vital interest. Several variables are involved in generation and propagation of impulse waves. Since mid-nineteenth century various studies in form of physical or numerical modeling or analytical studies have been carried out in order to classify and characterize these waves. Because of complication of physics of landslide generated impulse waves still not all influential parameters are fully recognized. In the present work first different types of water waves and nonlinear wave theories are briefly discussed (Fine et al., 2003).

## **2.5 Modeling of landslide to generated water waves**

Landslide generated tsunamis are physically modeled to study the tsunami wave characteristics and identify the dependence of the generated wave on the landslide parameters. The experiments involve assumptions from scaling laws and dimensional analysis. Physical models with perfect similitude require geometric, kinematic and dynamic similarity (Hughes, 1993). Geometric similarity requires the ratios of the length scales between model and prototype to be equal to one. In the case of tsunamis generated by landslides, the relevant forces are the inertial, gravitational, viscous, surface tension and elastic compression forces. Unless the model has the same scale as the prototype, no fluid may satisfy all of the force ratio requirements. Hence an important task before model experiments is to identify the important force ratio and to provide justification for neglecting the rest (Hudson et al., 1979). In the case of free surface flows, the most relevant force ratio is the Froude number, which is the ratio of the inertial forces to gravity forces. If the flow is governed by Froude similitude, then the Reynolds criterion including viscous forces, the Weber criterion including surface tension forces and the Cauchy criterion as the ratio of inertial to elastic forces can be neglected. Most of the experiments are performed at constant water depths thereby neglecting bathymetry effects. The physical modeling of landslide generated tsunamis or impulse waves are broadly classified based on the method used to describe or simulate the landslides and the dimensionality of the model (2D or 3D). They are solid block type landslide models, piston type landslide models and granular slide type landslide models. While block and granular models are gravity driven, piston models are forced motion (Kulikov et al., 1996).

### **2.5.1 Block (Rigid) Slide Modeling**

Landslides may be modeled as a solid block impacting the water surface vertically when dropped or moving on an incline. The simplest and the earliest experiments to study impulse waves were performed by holding a solid block above the surface of water and letting it fall freely into a water channel at one end. This classic plunger configuration was used by Russell (1837) and Russell (1844) to study the solitary wave.

### **2.5.2 Granular Slide Models**

Slingerland and Voight (1982) presented an empirical regression for the prediction of the relative wave amplitude of the first wave from the dimensionless kinetic energy. The experimental data was obtained from two 3-dimensional, site-specific physical model studies conducted at scales of 1:120 and 1:300 by Davidson and Whalin (1974), Davidson and McCartney (1975) and Ball (1970). The slides were either tabular or triangular in shape. The slide material consisted of gravel, iron or lead bags. The bags were moderately porous in nature with minimal deformation and perform like solid blocks with some porosity.

### **2.6 Modeling of Impulse Water Waves**

Prins (1958) modeled impulse waves with an initial dam-up or lowering of the water surface over a finite length in a 2D water channel. Four different wave types were generated depending on the amount and length of the initial rise or lowering of the water level relative to the water depth. The four wave types are: oscillatory waves, leading solitary waves followed by dispersive trailing waves, solitary waves separated from the trailing waves and multiple solitary waves. The experimental data were compared with the theoretical work of Nakano (1953) and Kranzer and Keller (1959), but the wave heights could not be predicted satisfactorily. Hunt (1988) produced an analytical solution for water waves generated by distant landslides by injecting a volume of fluid at a point source through the bottom of a reservoir. This approximation is justified by the assumption that the times are large relative to the duration of the time of the landslide and when the distances are large compared to a characteristic horizontal dimension of the volume flux of water displaced by the slide material.

Storr and Behnia (1999) conducted experimental studies on impulse waves generated by large diameter gravity driven liquid jets impacting into a pool with variable water depth. The liquid jets comprised of a finite volume of liquid released well above the still water surface from a cylinder with variable diameter. The viscosity of the liquid jet had a significant effect on the deformation of the jet during the impact and the size and shape of the air cavity formation.

LeMehaute and Wang (1995) extensively summarized the earlier work and literature on impulse wave generation by underwater explosions. The efficiency of the wave

generation increased from shallow waters to deeper waters. In shallow water depths, when the cavity generated by explosions reached the bottom, only 5% of the explosion energy was transmitted in the form of water waves. Similarities between explosion generated waves and the landslide generated impulse waves were proposed based on wave characteristics and air cavity collapse. In a similar study, Johnson and Bermel (1949) and Jordaan (1969) conducted laboratory experiments on underwater explosions by replacing the explosion with falling weights.

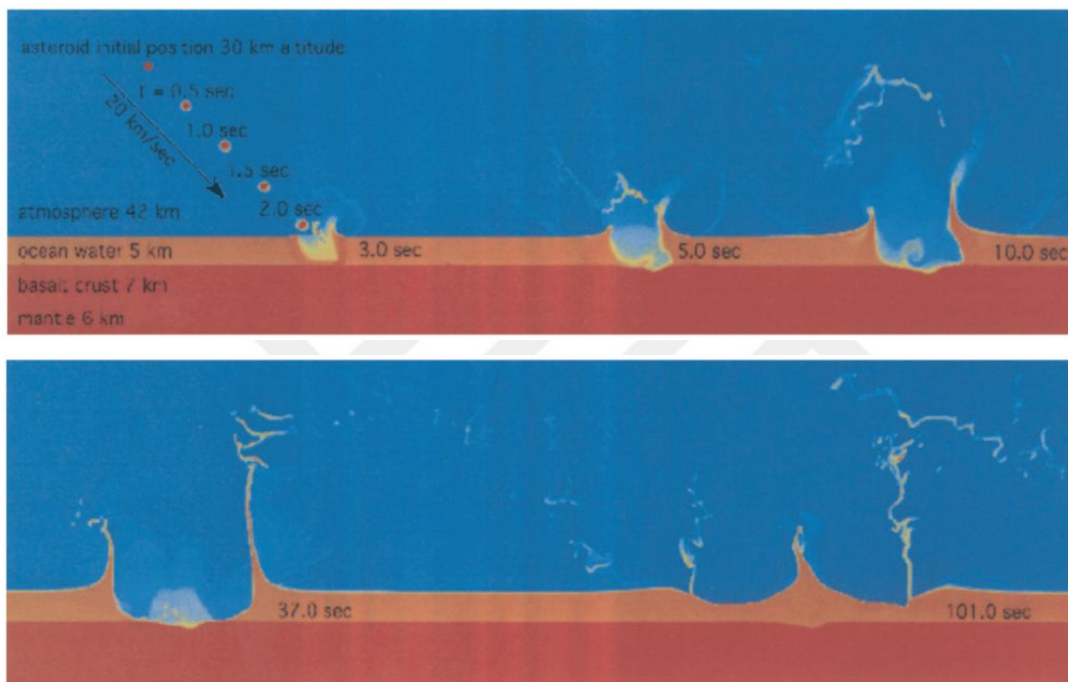


**Figure 2.4 :** A sequence of 10 images from the 3D simulation of an impact of 1 km bolides at an angle of  $45^\circ$ . Shown are the density rasters from Gisler et al. (2003).

Gisler et al. (2003) simulated impacts of asteroids into ocean using the SAGE model from Los Alamos National Laboratory shown in Figure 2.4. The model is a compressible Eulerian hydrodynamics code with continuous adaptive mesh refinement with realistic equations of state for atmosphere, water, the oceanic crust and the mantle. The wave generation and propagation from asteroid impacts are strongly influenced by nonlinearities, the material, size and direction of the asteroid and the oceanic environment. In most simulations, the deep ocean asteroid impact generated waves were not in shallow water waves but in the intermediate water depth range similar to landslide generated tsunamis. The simulations of asteroid impact

generated tsunami wave run-up and breaking can be found in Korycansky and Lynett (2005) and Korycansky and Lynett (2007).

## **2.7 Numerical Modeling of Landslide Generated Water Waves**

Noda (1970) used linear theory to predict the wave form of the wave motion produced by a body falling vertically into a tank. The model assumes that the time history of the falling block is known. The assumptions of linear theory breaks down near the falling block. The solution only produced reasonable agreement with experimental data for thin blocks with initial submergence. Even for initially submerged blocks, the theoretical solutions depart from the experimental data with increasing relative block thickness  $s/h$  and increasing wave amplitude.

Monaghan and Kos (2000) conducted 2D numerical simulations to clarify the details of the wave formation and the box dynamics from their experimental study. The setup for the numerical simulations were similar to the experimental setup. They successfully simulated the box dynamics and the wave formation including the wave breaking and air entrainment during cavity collapse with the Lagrangian particle method - smoothed particle hydrodynamics (SPH) described in Monaghan (1992). The numerical results overshoot the experiment by 3 - 18%. Monaghan and Kos (1999) successfully simulated gravity currents descending a ramp in a stratified tank with the SPH method. Further SPH simulations by Monaghan et al. (1999) accurately reproduced experiments on the run-up of a solitary wave on a beach of varying slope and in particular the wave breaking during the run-down including the bore formation. Heinrich (1992) conducted numerical studies on tsunamis generated by landslides using the NASA-VOF2D model. In this study, the landslides were modeled as a rigid body with a triangular cross section sliding down a ramp. The model is a nonlinear Eulerian model which solves the complete Navier-Stokes equations by a finite difference method. This model was extended to allow for the movement of the fluid domain boundaries to simulate landslides. Subaerial as well as submarine landslides and bottom movement were modeled using this code. While the first wave crest and trough showed good comparison the latter dispersive trains showed a phase shift and variations in the wave amplitude.

A three dimensional version of the model was also developed by Heinrich (1992). The NASA-VOF2D model was also used to simulate tsunamis generated by

submarine landslides by Rzedkiewicz and an P. Heinrich (1997). The submarine landslide was modeled as a fluid with an ideal Bingham plastic law, in which no deformation takes place until a specified shear is applied to the fluid.

## 2.8 Classification of Water Waves

Impulse waves include tsunamis generated in lakes or reservoirs and they belong to the group of surface gravity water waves.

Any displacement of the water surface from its equilibrium state can be identified as water waves. Water waves can be classified as oscillatory or translatory wave, from physical point of view. There is in the average no mass fluid transport for a pure oscillatory wave. On the other hand a pure translatory wave involves mass fluid transport in the direction of motion. Most of the times waves are a combination of both mentioned types. Water waves can also be categorized as shallow (e.g. earthquake generated tsunamis), intermediate, or deep (e.g. wind waves) water waves (Hager, 2009).

Shallow water waves are those waves with wave length  $L$  over water depth  $h$  is less than 2, intermediate water waves are the waves with  $2 \leq L/h \leq 20$ , and deep water waves are defined as waves with  $L/h < 2$  (Figure 2.5).

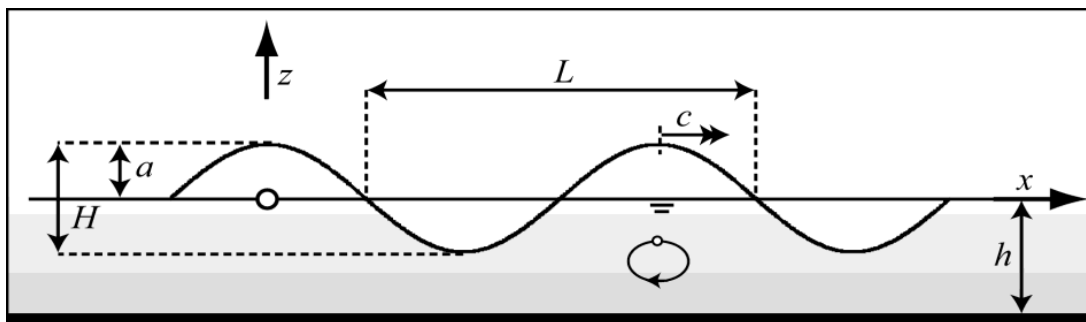


**Figure 2.5 :** Basic wave parameters illustrated for a pure oscillatory shallow water sinusoidal wave with closed particles orbits. With  $h$  indicating still water depth,  $H$  wave height,  $a$  wave amplitude,  $L$  wave length and  $c$  wave celerity (Hager, 2009).

Other than the mentioned classifications, water waves can be categorized as linear and non-linear waves from mathematical aspect. Linear wave theory which is also known as Airy theory (1845) and small amplitude wave theory. This theory is called linear because terms are of higher order such as  $(H/L)^2$  are neglected in calculation of

the relevant forces and parameters. In case of linear wave theory, wave profile is characterized by a sinusoidal shape and motion of the particles is oscillatory. Linear wave theory can be applied for shallow, intermediate and deep water (Figure 2.5). Linear wave theory is often applied in practice because of its simplicity and also because it is valid over a high range of initial criteria.

The general range of validity for linear wave theory is  $H/h < 0.03$  and  $H/L < 0.006$  (Dean and Dalrymple, 1991). Landslide generated impulse waves are typically highly nonlinear in the range of intermediate to shallow water waves with considerable fluid mass transport. Different types of nonlinear waves are characterized by different nonlinear wave theories. Herein four types of nonlinear waves which are more likely to conclude landslide generated impulse waves, are introduced; Stokes, Cnoidal, Solitary and Bore waves.

Stokes Waves are deep to intermediate water waves. Like linear waves, these waves also follow a periodic trend but water particles do not have a pure oscillatory motion and as a result a slight fluid mass transport occurs (Figure 2.6) (Dean and Dalrymple, 1991; CEM, 2008; Heller, 2008).

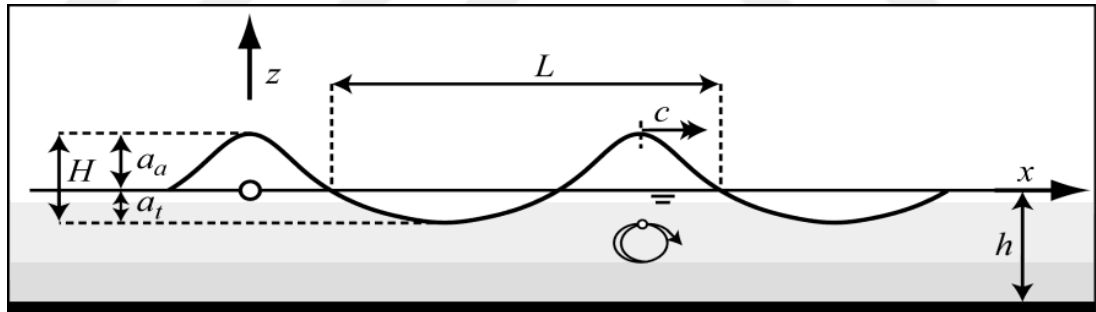


**Figure 2.6 :** Stokes wave profile with the basic parameters and open particle orbits (Dean & Dalrymple, 1991; CEM, 2008; Heller, 2008)

Cnoidal Waves, which include waves such as wind waves in shallow water, have first been identified by Korteweg and de Vries (1895). Cnoidal waves theory spans between linear wave theory and Solitary wave theory ( $T \rightarrow \infty$ ) ( $T$  indicating wave period). These periodic waves can be seen in intermediate to shallow water. Water particles move in open orbits and fluid mass transport occurs (Figure 2.7).

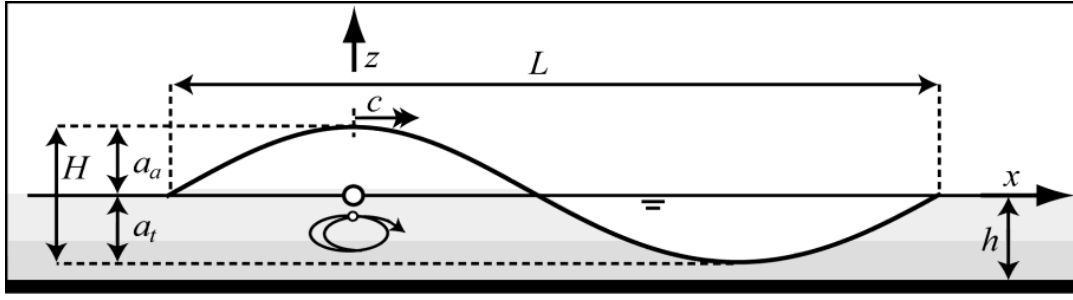


**Figure 2.7 :** Cnoidal wave profile with the basic parameters and open particle orbits (Dean & Dalrymple, 1991; CEM, 2008; Heller, 2008)

Solitary Waves are characterized by only a water surface elevation and no depression, in other word these waves do not have troughs. Particle movement is horizontal and as a result considerable fluid mass transport occurs in this case (Figure 2.8). A pure solitary wave can rarely be found in nature, however landslide generated tsunamis are best characterize by applying this theory (Dean & Dalrymple, 1991; CEM, 2008; Heller, 2008).

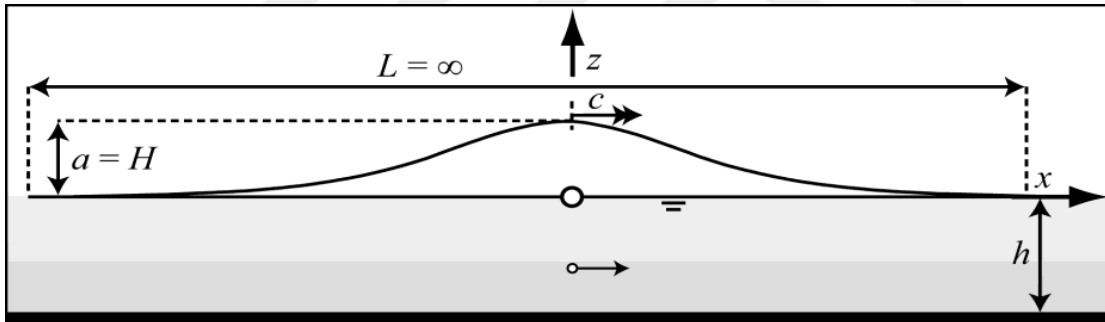


**Figure 2.8 :** Solitary wave profile with basic parameters and horizontal particles movement (Dean & Dalrymple, 1991; CEM, 2008; Heller, 2008)

Bore Waves are induced when amplitude of solitary wave exceeds the breaking limit. Bore waves can be found in shallow waters and are characterized by steep front and sloping back (Figure 2.9). Mass fluid transport occurs in case of bore waves because of horizontal particle movement.

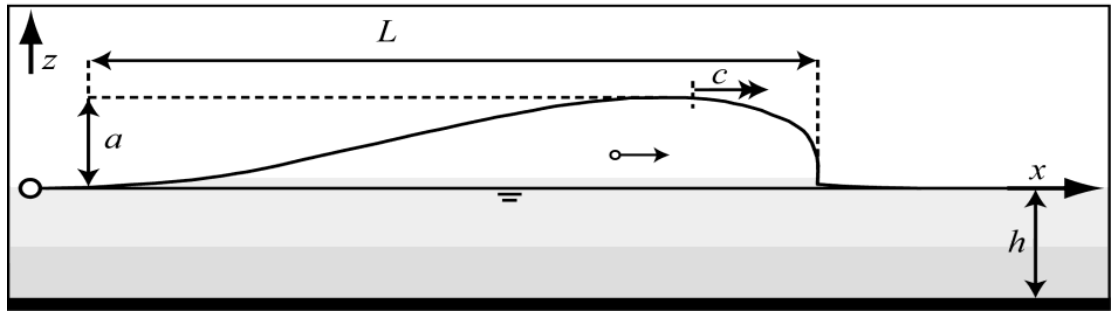


**Figure 2.9 :** Bore wave profile with the basic parameters and horizontal particle movement (Dean & Dalrymple, 1991; CEM, 2008; Heller, 2008)

The generation of impulse waves due to the impact of a subaerial landslide with water is a complex phenomenon, involving several physical aspects. Huber and Hager (1997) proposed a simplification of the considered phenomenon, individuating four distinct phases. Figure 2.10 shows the landslide starts moving, accelerates and then falls into water. The characterization and the forecasting of a landslide mechanism is a very complex task, involving lots of different aspects and physical variables. Step 2 sketches the impact of the landslide with water. This part of the process is at the bases of waves generation, due to the energy exchange mechanism between the landslide and the water. The principal landslide parameters, such as its volume, impact velocity, density, porosity, shape of the front, slope inclination angle, influence the features of the subsequent water wave motion.

In phase 3 impulse waves propagate in the reservoir or in the open sea, presenting a wave energy dispersion which is both longitudinal and directional. Wave's features change as a function of the water depth, and refraction, diffraction and shoaling may occur. Finally, phase 4 is related to the impulse wave interaction with shorelines or dams. The impulse wave run-up may cause the flood of coastal areas, and, in the case of an artificial reservoir, the dam can be overtopped thus flooding downstream areas.

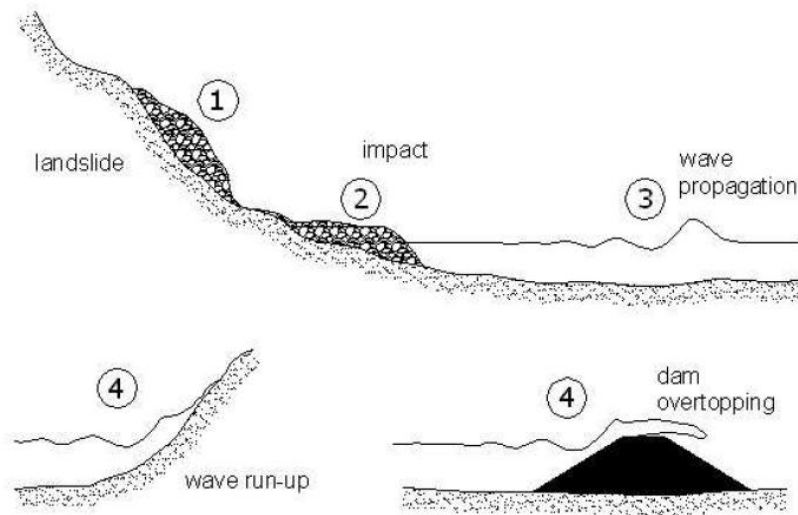


**Figure 2.10 :** Principal phases in the phenomenon of subaerial landslide generated waves (Dean & Dalrymple, 1991; Heller, 2008)

As far as the generated water waves are concerned, they may present very different shapes and dispersive features. Prins (1958), Wiegel et al. (1970) and Noda (1970) performed several physical experiments generating impulse waves by the falling of a solid block in a two dimensional wave flume. They concluded that, depending on the local water depth, the energy exchange between the landslide and the water, and the landslide volume, impact waves present different characteristics.

Another important aspect to be considered is the dynamic of the landslide itself, and not only the interaction between the landslide and the water. As one can imagine the phenomenon is very complex and its complexity lies also in the heterogeneity of the events that can occur (Figure 2.11).

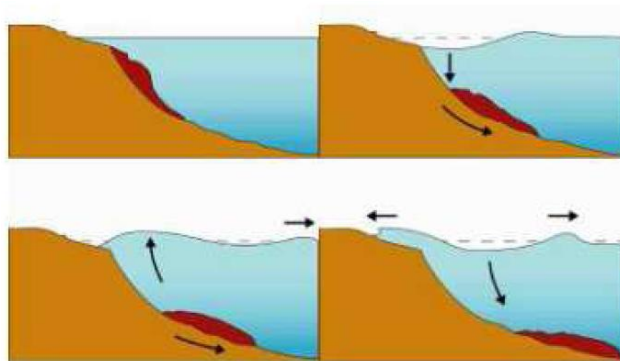


**Figure 2.11 :** Generation mechanism of submarine landslides generated waves (Wiegel et al. ,1970)

Estimation of landslide-generated wave's characteristics is of the utmost importance in the dam engineering and water reservoir planning. Any type of geophysical mass flow, in dam reservoirs, such as debris flows, debris avalanches, landslides, and rock falls may generate horrible impulsive waves that can cause serious damages to reservoir sidewalls, dam body, adjacent hydraulic structures, and agricultural or residential areas. Moreover, a huge sliding mass decreases the efficient capacity of dam reservoirs and initiates subsequent economical damages. For example, one of the most catastrophic rockslide-generated-impulsive waves in the world happened in the Vaiont reservoir in 1963, overtopping the arch dam by more than 100 m. The village of Longarone, located in the downstream of the dam, was completely destroyed with almost 3,000 fatalities. Therefore, it is very important to estimate the characteristics of landslide generated waves in dam reservoirs.

Four distinct stages can be distinguished in simulating landslide-generated waves in dam reservoirs: the generation, the propagation, the overtopping, and the run-up stages (Figure 2.12).

A large number of experimental and numerical studies have been conducted concerning the landslide-generated waves. A comprehensive review of these studies can be found in (Ataie-Ashtiani and Najafi-Jilani, 2006). The experimental studies are concerned about investigating effective parameters and characteristics of subaerial and submarine landslide-generated waves. In numerical studies, the developed models can be categorized according to their mathematical formulations as the Boussinesq-type models, models developed based on non-linear shallow water (NSW) wave equations and potential flow equations.

Furthermore, some researchers have utilized the developed numerical models for simulating landslide-generated waves in real cases. For example, Ataie-Ashtiani and Malek-Mohammadi (2007) proposed two new empirical equations for estimating the near-field wave amplitude and velocity of subaerial-landslide-generated waves based on the observed data of real cases. Then they used estimated first wave characteristics as input data of the numerical model for simulating three landslide scenarios of the Shafa-Roud dam reservoir.

In the previous research, a two-dimensional fourth-order Boussinesq type model developed by Ataie-Ashtiani and Najafi-Jilani (2007), entitled LS3D, is used for

simulating landslide-generated waves of two real cases. In numerical modeling, the main concern in various approaches is the accuracy of approximate equations to describe the nonlinearity effects and frequency dispersion of waves. Regarding this, the Boussinesq-type models are more efficient than models developed based on NSW waves or potential flow equations (Ataie-Ashtiani and Najafi-Jilani, 2007). The LS3D model has fourth order accuracy in considering the nonlinearity effects and frequency dispersion of waves (Ataie-Ashtiani and Najafi-Jilani, 2007). Furthermore, the present model is able to simulate the generation, the propagation, and the run-up stages.

The LS3D model was originally developed to study submarine landslide-generated waves. The model has recently been extended to be able to apply to the simulation of subaerial-landslide generated waves. The ability of the extended model in simulating subaerial-landslide-generated waves is validated using the available three-dimensional experimental data of Ataie-Ashtiani and Nik-khah (2008). The extended model is then applied to the Maku and Shafa-Roud dam reservoirs. Generated wave height, wave run-up, maximum wave height above the dam crest, and dam overtopping volume are estimated for two and three landslide scenarios, respectively.

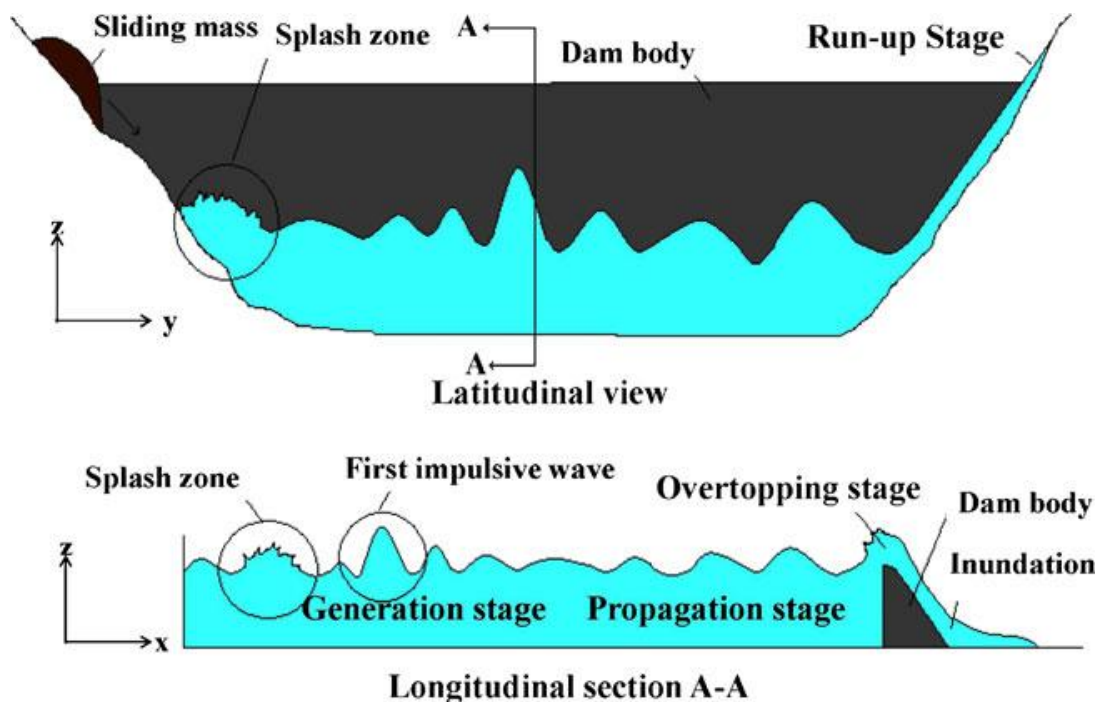


**Figure 2.12 :** Sketch illustrating separation of the generation, the propagation, the run-up, and the overtopping stages (Ataie-Ashtiani and Najafi-Jilani 2007)

Landslides may generate water waves of several hundreds of meters. Studies dealing with underwater landslides are relevant for the present investigation.

Figure 2.13(a) shows the governing parameters for the 2D impulse wave generation in the  $(x; z)$  plane. The slide is characterized by the slide thickness  $s$ , the slide length  $l_s$ , the slide impact velocity  $V_s$ , the bulk slide volume  $V_s$  or the slide grain volume  $V_g$ , the slide mass  $m_s$ , the bulk slide porosity  $n$ , the bulk slide density  $\rho_s$ , the grain diameter  $d_g$ , slide impact angle  $\alpha$ , the slide front angle  $\phi$ , and the slide width  $b$  as shown in Figure 2.13(a).

The impulse waves are characterized by the water surface displacement  $\eta$ , the maximum wave height  $H_M$  and the wave amplitude  $a_M$ , and the wave celerity  $c$ .

3D models are based on the same parameters as 2D models except for the wave propagation angle  $\gamma$  and the radial distance  $r$  replacing the stream wise coordinate  $x$ , as shown in Figure 2.13(b).

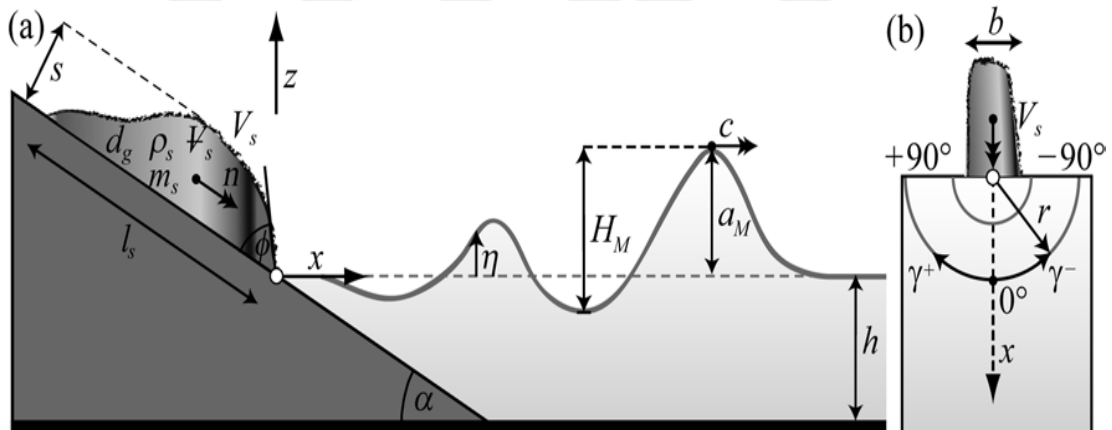


**Figure 2.13 :** Definition of the governing parameters and the impulse wave characteristics for (a) 2D and (b) additional parameters for 3D impulse wave generation (Ataie-Ashtiani and Najafi-Jilani 2007)

## 2.9 Equations of Waves Generation by Submarine and Subaerial Landslides

Surface wave generation by a moving slide is affected by the water depth, gravity, and fundamental characteristics of the slide. The principal mechanism for energy transfer from the slide motion to the surface waves, water displacement, is readily incorporated using the long-wave (shallow-water) approximation. The main assumptions for the present models (viscous and rigid-body) are the following:

(1) The surface waves and slides satisfy the long-wave (hydrostatic) approximation, implying that the wavelength of the water waves is much greater than the water depth, and that the width and length of the viscous slide is much greater than the slide thickness.

(2) The viscous slide is an incompressible, isotropic, laminar, quasi-steady viscous fluid; the viscous regime is rapidly reached in any failure and in the steady-state regime, the horizontal velocities have a parabolic vertical profile.

(3) The rigid-body slide moves as a non-deformable body with given friction.

(4) The seawater is an incompressible inviscid fluid.

We use standard Cartesian coordinates  $x, y, z$ , with  $z$  measured vertically upward. For time  $t$ , the upper (water) layer consists of seawater with density  $\rho_1$ , surface elevation  $\eta(x, y, t)$ , and horizontal velocity  $u$  with components  $u$  and  $v$  (Figure 2.14a). The lower layer consists of viscous sediments (or rigid body) having density  $\rho_2$ , dynamic viscosity  $\mu$  (or friction coefficient  $k$  in case of a rigid body), and horizontal velocity  $U$  with components  $U$  and  $V$ . Both the slope and the slide have small angles, so the motion is essentially horizontal. The slide is bounded by an upper surface  $z = -h(x, y, t)$  and the seabed surface  $z = h_s(x, y)$ , giving the slide thickness as  $D(x, y, t) = h_s(x, y) - h(x, y, t)$ ,

A schematic of the computational amplitude for a landslide with a subaerial part is introduced in Figure 2.14. The domain consists of four zones: (1) The dry coastal area,  $D$ ; (2) the dry portion of the slide,  $SD$ , corresponding to the subaerial part of the slide; (3) the wet portion of the slide,  $SW$ , corresponding to the submarine part of the slide; and (4) the water,  $W$ . The numerical model must account for the time-varying changes in the areas and locations of these zones.

Our purpose is to construct the non-linear, vertically integrated Navier-Stokes equations for the landslide.

We assume that the landslide occupies a domain from  $z = -h_s(x, y)$  to  $D(x, y, t) = h_s(x, y) - h(x, y, t)$ . We assume that the landslide rapidly reaches a steady shape so that we can use a locally parabolic approximation in the vertical to describe

the horizontal velocities,  $U_m(x, y, z; t)$  and  $V_m(x, y, z; t)$ ; specifically, (Fine et al., 2003)

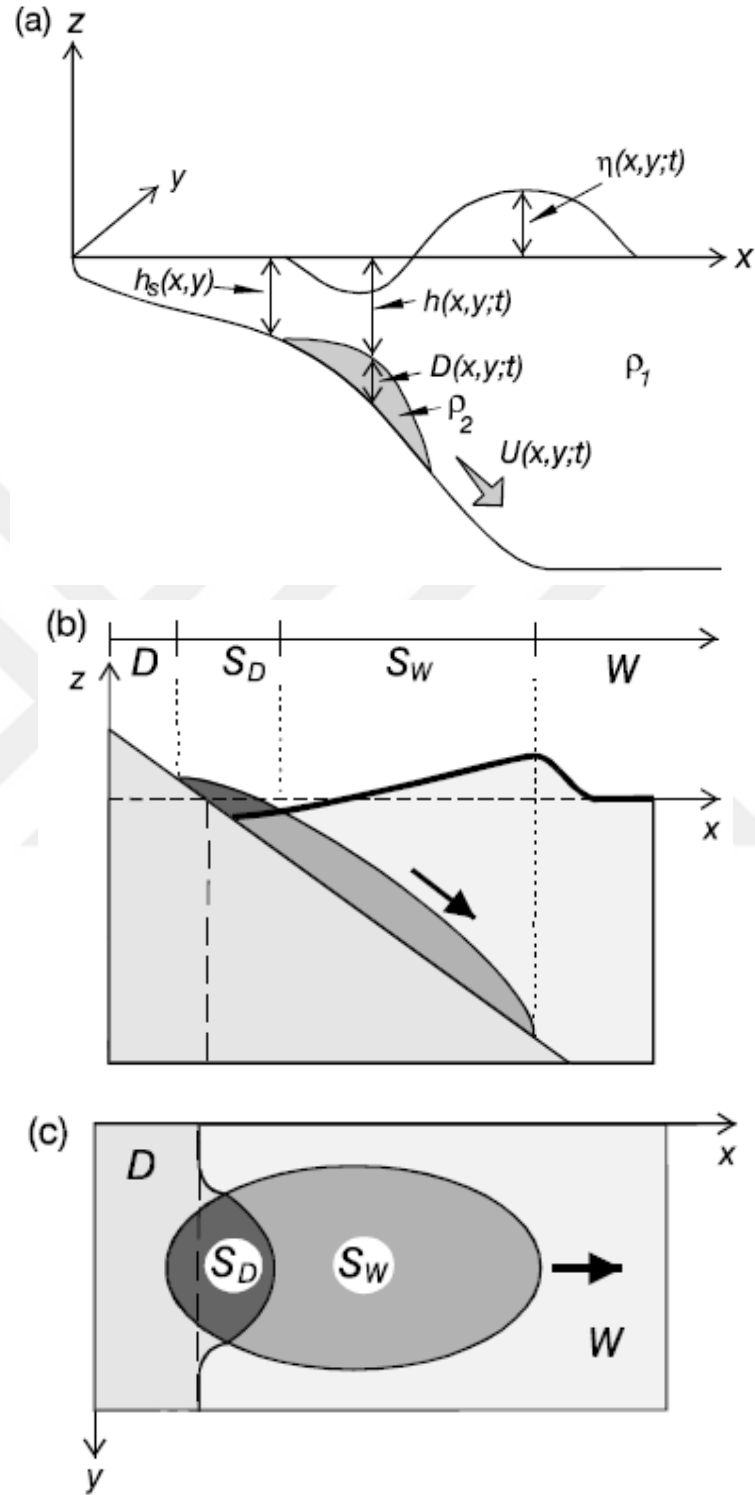


**Figure 2.14 :** (a) Sketch of a submarine landslide with density  $\rho_2$ , thickness  $D$ , and water depth  $h$ , and associated surface waves of height  $\eta$ . (b) Side view, and (c) plan view of a combined subaerial and submarine slide (Fine et al., 2003).

$$U_m(x, y, z; t) = U(x, y; t)(2\xi - \xi^2) \quad (2.1a)$$

$$V_m(x, y, z; t) = V(x, y; t)(2\xi - \xi^2) \quad (2.1b)$$

where  $\xi = (z + h_s) / D$ . The equations for conservation of mass and momentum for a viscous submarine slide have the form (Fine et al., 2003):

$$\frac{\partial D}{\partial t} + \frac{2}{3} \left[ \frac{\partial(DU)}{\partial x} + \frac{\partial(DV)}{\partial y} \right] = 0 \quad (2.2)$$

$$\rho_2 \frac{2}{3} \left[ \frac{\partial U}{\partial t} - \frac{1}{5} \frac{U}{D} \frac{\partial D}{\partial t} + \frac{4}{5} \left( U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} \right) \right] = -g \left[ (\rho_2 - \rho_1) \left( \frac{\partial D}{\partial x} - \frac{\partial h_s}{\partial x} \right) + \rho_1 \frac{\partial \eta}{\partial x} \right] - \frac{2\mu U}{D^2} \quad (2.3a)$$

$$\rho_2 \frac{2}{3} \left[ \frac{\partial V}{\partial t} - \frac{1}{5} \frac{V}{D} \frac{\partial D}{\partial t} + \frac{4}{5} \left( U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} \right) \right] = -g \left[ (\rho_2 - \rho_1) \left( \frac{\partial D}{\partial y} - \frac{\partial h_s}{\partial y} \right) + \rho_1 \frac{\partial \eta}{\partial y} \right] - \frac{2\mu V}{D^2}. \quad (2.3b)$$

The first equation is the continuity equation (2.2). However, the momentum equations (2.3a) and (2.3b) are slightly different from those presented by Jiang and LeBlond as a result of corrections to several of the constant coefficients in the terms in the square brackets on the left-hand sides of these equations (Fine et al., 2003).

For a subaerial slide, it is useful to introduce a new variable,  $h_w$ , the full water thickness ( $h_w = \eta + h = \eta - D + h_s$ ), and to present equations (2.3a) and (2.3b) in the form (Fine et al., 2003):

$$\rho_2 \frac{2}{3} \left[ \frac{\partial U}{\partial t} - \frac{1}{5} \frac{U}{D} \frac{\partial D}{\partial t} + \frac{4}{5} \left( U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} \right) \right] = -g \left[ \rho_2 \left( \frac{\partial D}{\partial x} - \frac{\partial h_s}{\partial x} \right) + \rho_1 \frac{\partial h_w}{\partial x} \right] - \frac{2\mu U}{D^2}; \quad (2.4a)$$

$$\rho_2 \frac{2}{3} \left[ \frac{\partial V}{\partial t} - \frac{1}{5} \frac{V}{D} \frac{\partial D}{\partial t} + \frac{4}{5} \left( U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} \right) \right] = -g \left[ \rho_2 \left( \frac{\partial D}{\partial y} - \frac{\partial h_s}{\partial y} \right) + \rho_1 \frac{\partial h_w}{\partial y} \right] - \frac{2\mu V}{D^2}. \quad (2.4b)$$

For the subaerial zone,  $S_D$ , we have the particular case of zero water thickness,  $h_w = 0$ , for which equations (2.4a) and (2.4b) describe slide motion on a dry coast.

The above equations are solved subject to the condition of zero transport through the coastal boundary (G) and require that the slide does not cross the outer (open) boundary. The condition of no volume transport through the coast gives

$$U_n = 0 \text{ on } G \quad (2.5)$$

where  $U_n$  is the normal slide velocity. The initial slide has a rectangular bottom periphery oriented at a given angle  $\beta$  and, as noted above, is assumed to have a parabolic cross-section.

### 2.9.1 Surface Waves

For surface waves generated by a submarine slide, the water motions are nearly horizontal and the pressure is hydrostatic (long-wave approximation). The nonlinear shallow-water equations then have the form (Fine et al., 2003):

$$\frac{\partial h_w}{\partial t} + \frac{\partial(h_w u)}{\partial x} + \frac{\partial(h_w v)}{\partial y} = 0; \quad (2.6)$$

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial v}{\partial y} = -g \frac{\partial \eta}{\partial x}; \quad (2.7a)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -g \frac{\partial \eta}{\partial y}, \quad (2.7b)$$

which are applicable to wet zones,  $S_W$  and  $W$  (see Figure 2.14c). At the shore (boundary G), we assume a vertical wall with zero normal velocity:

$$U_n = 0 \text{ on } G \quad (2.8)$$

At the open boundary (  $\Gamma$  ), the one-dimensional radiation condition for outgoing waves is:

$$\frac{\partial \eta}{\partial t} = \text{sgn}\left(\frac{\partial \eta}{\partial t}\right) \sqrt{gh - \left[\left(\frac{\partial \eta}{\partial x}\right)^2 + \left(\frac{\partial \eta}{\partial y}\right)^2\right]} \quad (2.9)$$

At the initial time,  $t = 0$ , both the slide and the sea surface are at rest (Fine et al., 2003).

The governing equations to describe the flow of two incompressible Newtonian fluids (e.g., water and mudslide, see Figure 2.15) on domain  $\Omega(t)$  are the incompressibility condition equation, (Fine et al., 2003),

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (2.10)$$

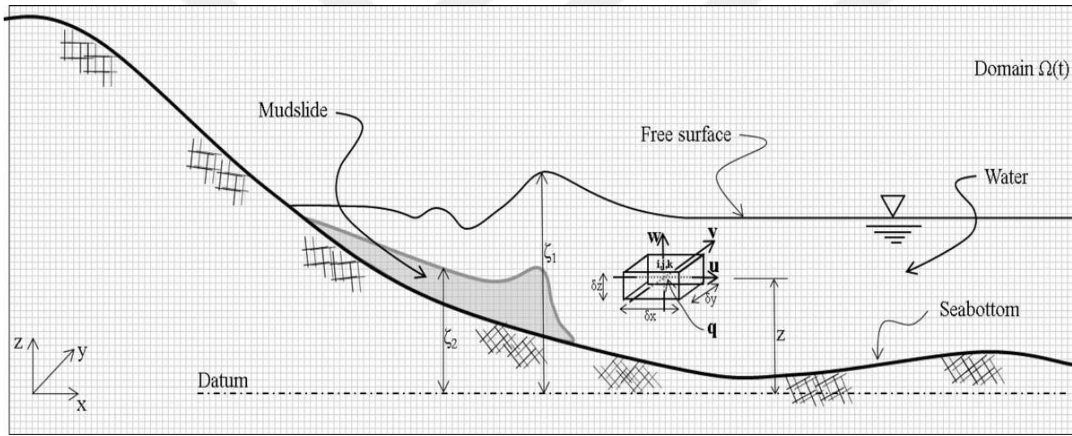


**Figure 2.15 :** Model domain sketch (Campbell et al., 1995)

which results from the continuity equation when the density is constant, and the non-conservative equation of momentum given by (Campbell et al., 1995):

### 2.9.2 For The Water Phase

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = & -g \frac{\partial \eta_1}{\partial x} - \frac{1}{\rho_1} \frac{\partial q}{\partial x} + \frac{\partial}{\partial x} \left[ \frac{\mu_1}{\rho_1} \left( 2 \frac{\partial u}{\partial x} \right) \right] \\ & + \frac{\partial}{\partial y} \left[ \frac{\mu_1}{\rho_1} \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] + \frac{\partial}{\partial z} \left[ \frac{\mu_1}{\rho_1} \left( \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right] \end{aligned} \quad (2.11)$$

$$\begin{aligned} \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = & -g \frac{\partial \eta_1}{\partial y} - \frac{1}{\rho_1} \frac{\partial q}{\partial y} + \frac{\partial}{\partial x} \left[ \frac{\mu_1}{\rho_1} \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right] \\ & + \frac{\partial}{\partial y} \left[ \frac{\mu_1}{\rho_1} \left( 2 \frac{\partial v}{\partial y} \right) \right] + \frac{\partial}{\partial z} \left[ \frac{\mu_1}{\rho_1} \left( \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right] \end{aligned} \quad (2.12)$$

$$\begin{aligned} \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = & -\frac{1}{\rho_1} \frac{\partial q}{\partial z} + \frac{\partial}{\partial x} \left[ \frac{\mu_1}{\rho_1} \left( \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right] \\ & + \frac{\partial}{\partial y} \left[ \frac{\mu_1}{\rho_1} \left( \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z} \right) \right] + \frac{\partial}{\partial z} \left[ \frac{\mu_1}{\rho_1} \left( 2 \frac{\partial w}{\partial z} \right) \right] \end{aligned} \quad (2.13)$$

where  $u(x,y,z,t)$ ,  $v(x,y,z,t)$ , and  $w(x,y,z,t)$  are the velocity components along the coordinate axes of the fluid at point  $x=x_i+y_j+z_k$  and time  $t$  (Campbell et al., 1995). Here, subscript 1 indicates physical parameters or variables corresponding to the water phase, i.e.,  $\eta_1(x,y,t)$  is the water-surface elevation measured from the vertical datum,  $\rho_1$  is the density of the water, and  $g$  is the acceleration due to gravity. Considering the water phase as a Newtonian fluid, the kinematic viscosity  $\eta_1=\rho_1$  can be adjusted to give the best possible agreement with the reference data. The total pressure,  $p=p_{hyd}+q$ , has been divided into a hydrostatic pressure (Campbell et al., 1995):

$$p_{hyd} = \rho_1 g (\eta_1 - z) \quad (2.14)$$

and the non-hydrostatic pressure  $q$  such that  $\partial p_{hyd} / \partial z = -\rho_1 g$ . Here,  $z$  is the elevation measured from the vertical datum to the cell center.

### 2.9.3 For The Mudslide Phase

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = & -g \left( \alpha \frac{\partial \eta_1}{\partial x} + (1-\alpha) \frac{\partial \eta_2}{\partial x} \right) \\ & - \frac{1}{\rho_2} \frac{\partial q}{\partial x} + \frac{\partial}{\partial x} \left[ \frac{\mu_2}{\rho_2} \left( 2 \frac{\partial u}{\partial x} \right) \right] + \frac{\partial}{\partial y} \left[ \frac{\mu_2}{\rho_2} \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right] \\ & + \frac{\partial}{\partial z} \left[ \frac{\mu_2}{\rho_2} \left( \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right] \end{aligned} \quad (2.15)$$

$$\begin{aligned} \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = & -g \left( \alpha \frac{\partial \eta_1}{\partial y} + (1-\alpha) \frac{\partial \eta_2}{\partial y} \right) - \frac{1}{\rho_2} \frac{\partial q}{\partial y} \\ & + \frac{\partial}{\partial x} \left[ \frac{\mu_2}{\rho_2} \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) \right] + \frac{\partial}{\partial y} \left[ \frac{\mu_2}{\rho_2} \left( 2 \frac{\partial v}{\partial y} \right) \right] + \frac{\partial}{\partial z} \left[ \frac{\mu_2}{\rho_2} \left( \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right] \end{aligned} \quad (2.16)$$

$$\begin{aligned} \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = & -\frac{1}{\rho_2} \frac{\partial q}{\partial z} + \frac{\partial}{\partial x} \left[ \frac{\mu_2}{\rho_2} \left( \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right] \\ & + \frac{\partial}{\partial y} \left[ \frac{\mu_2}{\rho_2} \left( \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z} \right) \right] + \frac{\partial}{\partial z} \left[ \frac{\mu_2}{\rho_2} \left( 2 \frac{\partial w}{\partial z} \right) \right] \end{aligned} \quad (2.17)$$

(Campbell et al., 1995) where subscript 2 represents physical parameters and variables corresponding to the mudslide phase.  $\eta_2(x,y,t)$  is the mudslide-surface elevation measured from the vertical datum,  $\rho_2$  is the mudslide material density, and  $\alpha$  is the water-mudslide density ratio given by  $\rho_1/\rho_2$  (Horrillo, 2013).

## 2.10 Landslide Motion in Air And Water

The motion of a subaerial landslide is typically divided into three phases: (i) after triggering, the slide propagates over some distance, only interacting with air; (ii) the slide penetrates water, while a part of it still interacts with air; and (iii) the whole slide becomes submerged in water and its effect on the free surface decreases with time.

In this section, we aim at separately validating the model for the first and third phases of motion of a subaerial rigid slide. The second phase will be addressed in the next section (part III, section B). For those two phases, the slide is only surrounded by one fluid, either air or water, and the free surface influence on its motion is small and hence can be neglected in this validation. Note that basal friction, which may play an important role in this phenomenon in natural conditions, is neglected here to focus on slide/water interaction phenomena. The effect of basal friction could easily be introduced in the model by simply reducing gravity in the rigid slide by an amount corresponding to global frictional effects. Figure 2.16 shows the fluid domain considered in these computations, which consists of a rectangle of length  $L_d = 7$  m and height  $H_d = 0.75$  m. The slide shape is semi-elliptical, with length  $L = 1$  m, and thickness  $S=0.25$ , similar to the model slide used in the earlier submarine/subaerial

landslides experiments of Grilli and Watts (1999, 2005), which will be used as a reference to estimate hydrodynamic parameters such as drag or added mass coefficient. As shown in Figure 2.16, to simulate a slide moving down a plane slope in the model, the gravity vector is set at an angle  $\alpha$  with respect to the  $z$  direction.

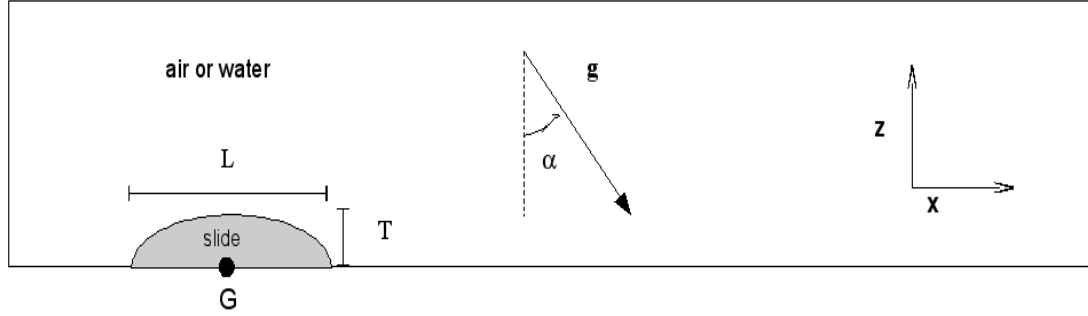


**Figure 2.16 :** Sketch of the slide case simulated (Grilli, 1999 and Watts, 2005)

### 2.11 2D Case - Heinrich (1992) Experiments

Heinrich (1992) performed experiments, in which a triangular (0.5 m x 0.5 m) rigid block with a 105 kg mass freely slid down. The water depth was 1 m and the top of the block was initially located 1 cm below the undisturbed free surface. Free surface displacements induced by the sliding block were measured as a function of time, using an optical camera. In the model, the physical domain is represented by an 8 m x 8 m square, in which gravity is inclined at  $45^\circ$  from vertical (Figure 2.17). This particular configuration allows for easily setting the free slip boundary condition under the slide. The channel bottom is simulated as a porous medium, for which porosity tends to zero, thus imposing zero velocity for the fluid within it. The computational grid consists of regular cells, with  $\Delta x'/L = \Delta z'/L = 1.8\%$  ( $L = 0.707$  m), for  $x' < 5$  m and  $z' < 5$  m, exponentially increasing in size beyond those dimensions. Time-step is set to 0.005 s for the first 50 iterations and then automatically computed using a maximum mesh Courant number of 0.5. Free-slip boundary conditions are specified for the velocity components along all boundaries.

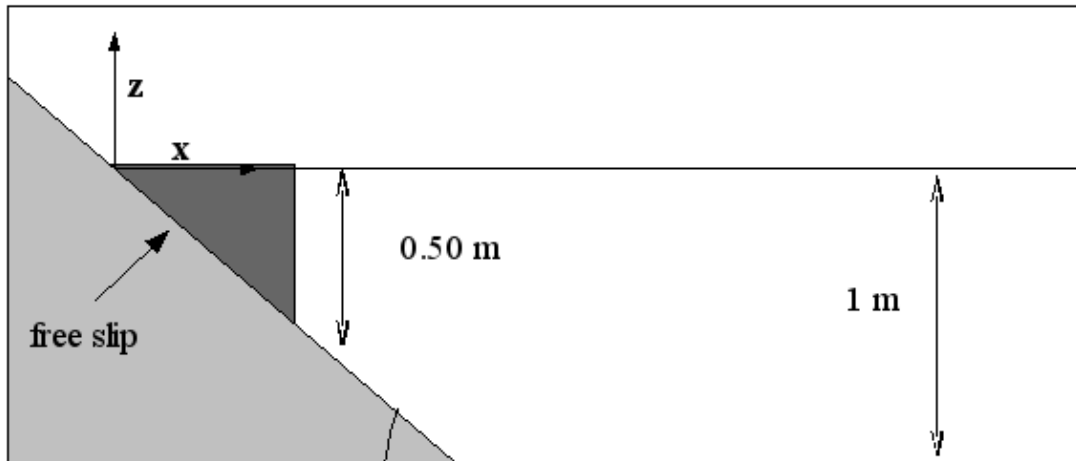


**Figure 2.17 :** Sketch of Heinrich's (1992) experiment for a solid triangular block sliding down an incline

### 2.12 3D Case – Liu et al. (2005) Experiments

Wu (2004) and Liu et al. (2005) carried out experiments in a large scale flume to study the wave field and subsequent run-up generated by a sliding three dimensional rigid wedge. These experiments were also selected as a benchmark for numerical models, as part of the 3rd international workshop on long wave run-up models (Catalina, 2004) as well as within the project TRANSFER (Tsunami Risk And Strategies For the European Region).

Liu et al. (2005), performed 3D-LES simulations, using the PLIC VOF method, and compared numerical results to their experimental data. They prescribed the slide motion in the model, based on the measured slide displacement, with the slide being close to the free surface at initial time. Upon slide release, free surface deformation is strong and wave breaking is susceptible to occur in certain cases. Complex flow patterns occur in all cases.

### **3. METHOD**

#### **3.1 Introduction**

Flow-3D software package is used to examine the hydraulic performance and efficiency of the system. The fundamental and basic laws of mass, momentum and energy conservation were adopted in which the finite difference method was applied to solve and analyze these equations. The numerical model we will use in this study is the full three dimensional 3D commercial code FLOW-3D.

The foundation of the solver is a finite volume or finite difference formulation, in an Eulerian framework, of the equations describing the conservation of mass, momentum, and energy in a fluid. The code can simulate and analyze two-fluid problems, incompressible and compressible flow, and laminar and turbulent flows (Figure 3.1).

The numerical calculations are accomplished with FLOW-3D. This 3D-numerical software is a good solution for flow calculation with free surface and is based on the Reynolds Averaged Navier–Stokes (RANS) equations in combination with the Volume of Fluid (VOF) technique (Flow Science, Inc., 2014; Hirt and Nichols, 1981).

The software works with mesh blocks based on orthogonal rectangular grids, which are very easy to generate and estimate and compute. The use of structured, rectangular cells leads to the numerical advantage that all indices for neighbouring elements are known and no additional neighbour list has to be stored.

In contrast to body-fitted coordinate elements, a solid surface can cut through an element as a plane in FLOW-3D (Flow Science, Inc., 2014; Gabl et al., 2014a). The original geometry is modified based on the chosen grid.



**Figure 3.1 :** Flow-3D software package (3-D numerical software) (FLOW-3D Academic Program - Flow Science, 1980)

### 3.2 Advantages of FLOW-3D Software

FLOW-3D has the ability to ignore the air surrounding the flowing water by using the volume of fluid (VOF) method developed. This method also allows the numerical model to create a sharp interface between the water and air without using the fine meshes required by other computational fluid dynamics (CFD) software. Another method, known as fractional area volume obstacle representation (FAVOR) method, is also a trademark of FLOW-3D.

It allows the program to use fully structured grids that are very easy to generate throughout the entire flow domain. FLOW-3D utilizes a finite difference solution scheme and has the ability to calculate solutions using various implicit and explicit solver options. The ability of using multiple and nested meshes as well as the re-run capability available in FLOW-3D are other options that make the numerical model suitable for permeable pavement modeling.

Numerical solutions to the problems based on the full Reynolds Averaged Navier-Stokes equations (RANS) with the Volume of Fluid surface tracking method (RANS/VOF) have indeed been thoroughly tested, and have found their way into engineering practice (FLOW-3D Academic Program - Flow Science, 1980).

FLOW-3D incorporates a special technique, known as the FAVOR™ (Fractional Area Volume Obstacle Representation) method, which is used to define general

geometric regions within the rectangular grid. The philosophy behind FAVOR™ is that numerical algorithms are based on information consisting of only one pressure, one velocity, one temperature, etc., for each control volume, so it would be inconsistent to use much more information to define the geometry. Thus, the FAVOR™ technique retains the simplicity of rectangular elements while representing complex geometric shapes at a level consistent with the use of averaged flow quantities within each volume element.

FLOW-3D offers a multitude of meshing capabilities that are designed to be simple yet efficient and robust in modeling complex flows. While the simplicity of meshing can be attributed to the structured mesh that is used by FLOW-3D, the efficiency and robustness is achieved by various features enabled by multi-block meshing. The use of multiple mesh blocks allows local refinement in areas of interest and significantly reduces computational resources required for a given simulation. Small obstacles, complex geometries and thin channels that are small compared to the overall domain size can be accurately resolved using one of the several multi-block meshing capabilities such as; linked, nested, conforming, and/or partially overlapping mesh blocks. Linked mesh blocks can be used only to mesh the areas of interest and limit the total number of computational cells. Nested mesh blocks can be used to enhance the resolution around an area of interest. Conforming and partially overlapping mesh blocks can be used to resolve irregularly shaped fine features with sharp changes in scale that otherwise cannot be simply resolved using nested mesh blocks. FLOW-3D also allows body-fitted finite element meshes to model Fluid-Structure Interaction. These body-fitted meshes can be automatically generated with FLOW-3D or imported from external CAD packages. All these meshing techniques gives users the flexibility to create meshes that are simple and yet efficient, thereby improving solver performance and reducing simulation turnaround time.

The conforming mesh capability has been extended so that an active computational region of an arbitrary shape can be defined. This is achieved through the use of a new type of geometry component called meshing component that defines a region in the computational domain, spanning both open and solid volumes, which a mesh block can conform to. Meshes conforming to a new type of component called meshing components are available under the Meshing tree once a meshing component has been added to the simulation.

The wave absorbing feature that uses geometry components of the Wave Absorbing type has been complemented by the addition of wave absorbing layers or rectangular shapes adjacent to outflow and continuative mesh boundaries. This addition greatly simplifies the definition of wave damping regions in the computational domain. The more general approach of placing wave absorbing components anywhere in the domain has been retained.

The ability to define stretched meshes in FLOW-3D can lead to visualization issues when displaying velocity vectors. For example, if the mesh is highly concentrated in one area, a uniform vector field can be completely obscured due to the high vector density whereas in other areas the vector field may be sparse. In these cases, changing the vector display density doesn't help since this change is applied uniformly. A new option to display the vectors on 2D clips uniformly solves this problem. This new option is available as "Show on Uniform Grid" under the Velocity Vectors option on 2D clips.

As a general-purpose CFD package, FLOW-3D has an extensive array of physical and numerical capabilities that have been developed and perfected over its 35-year history, such as incompressible free-surface internal and hypersonic external flow, heat transfer, turbulence, moving and deforming solids, surface tension and phase change. These models allow our users to successfully apply FLOW-3D to solve a wide range of engineering and scientific problems, optimize designs and gain insight into complex processes, all in the quest to improve the world through accurate flow modeling.

Many types of granular media are encountered in processing and manufacturing industries. Because of its unusual properties, granular material can often pose difficult problems for engineers seeking to transfer, mix or otherwise manipulate it for useful purposes. A good example of a granular flow process arises in the making of sand cores for metal casting applications.

A model has been developed for flows of highly concentrated granular material. The model uses a "continuum" approach, that is, it is based on a continuous fluid representation of the sand, making no attempt to treat individual sand particles.

A mixture of sand and air, is a two-phase flow in which the air and sand materials flow with their individual velocities, but are coupled through momentum exchanges

resulting from pressure and viscous stresses. In typical core sands the diameters of sand particles are on the order of tenths of millimeters and the volume fraction of the sand that is blown into a core box is generally 50% or higher. In this range a strong coupling exists between the sand and air so their mixture can be modeled as a single, composite fluid. Two-phase effects resulting from differences in the velocities of the two materials are accounted for using an approximation for their relative velocity that is referred to as a Drift-Flux.

This composite and relative velocity approach has been selected as the basis for the granular media model. It is assumed that the sand/air mixture can be represented as a single fluid with a sharp free surface at its boundary with the surrounding air. The composite fluid, however, is allowed to have a non-uniform density, depending on the degree of sand compaction. The viscosity of the mixture is a function of density and shear stress. Because the majority of momentum transfer is by particle-particle collisions the sand-air mixture has the character of a shear thickening material.

For the purpose of including vents in a core box all pure air regions (also referred to as void regions) are treated as adiabatic bubbles. An adiabatic bubble is a region of air surrounded by fluid or solid walls. The pressure in a bubble is a function of the bubble volume and has a uniform value over the region occupied by the bubble. Vents in a core box allow air within bubbles to be vented to the exterior of the box.

To illustrate some of the differences that can occur in a granular material as opposed to a fluid, a simple two-dimensional wedge shape hopper was set up with a 1 cm wide tube at the bottom. The simulation is started with the bottom tube empty.

### **3.3 Reasons for Choosing Flow-3D Software**

In a FLOW-3D simulation, a general moving object (GMO) is a rigid body with any kind of motion that is either user-prescribed or dynamically coupled with fluid flow. It can have six-degrees-of-freedom or motion constraints such as a fixed axis/point. Prescribed forces and torques can be applied on a GMO under coupled motion. The GMO model allows multiple rigid bodies under independent motion types as well as rigid body interactions including collisions and continuous contact. The model is robust, efficient and powerful and is the only one of its kind in commercial computational fluid dynamics software.

FLOW-3D is a powerful modeling tool that gives modelers valuable insights into physical flow processes, with special capabilities for accurately predicting free-surface flows. FLOW-3D's combination of both accuracy and speed provide engineers optimized design and production processes.

The model has already been successfully used to study the interaction of waves and structures. FLOW-3D, expanded by Flow Sciences, is a general aim computational fluid dynamics simulation and imagery software package expanded at Los Alamos National Laboratory in the 1960s and 1970s.



## **4. MODELING OF GENERATED WATER WAVES**

### **4.1 Introduction**

Flow-3D software package is used to examine the hydraulic performance of the system. The fundamental laws of mass, momentum and energy conservation were adopted in which the finite difference method was applied to solve these equations. The numerical model used in this thesis is the full three dimensional commercial code FLOW-3D.

The model has already been successfully used to study the interaction of waves and structures. FLOW-3D, developed by Flow Sciences, is a general purpose computational fluid dynamics simulation software package developed at Los Alamos National Laboratory in the 1960s and 1970s. The basis of the solvers of FLOW-3D is a finite volume or finite difference formulation, in an Eulerian framework, of the equations describing the conservation of mass, momentum, and energy in a fluid. The physical scale model of this study has been carried out to provide a data set to verify the three-dimensional numerical model. In order to make a good comparison possible, the numerical model should use the similar model parameters as have been used in the physical scale model. So, we now simulate the generation of waves by a subaerial landslide, with Flow 3D software. The obtained results by the numerical method include the amounts of wave height, time history of free surface fluctuations in different locations, and wave propagation for different landslide geometries .

In FLOW-3D, there are five turbulence models available: the Prandtl mixing length model, the one-equation, the two-equation  $k-\epsilon$  (kinetic energy,  $k$  and dissipation rate,  $\epsilon$ , the  $k-\omega$  two-equation model in FLOW-3D is thus suitable for modeling free shear flows with streamwise pressure gradients like spreading jets, wakes, and plumes) (Wilcox, 1988), RNG models, and a large eddy simulation, (LES), model. In this thesis turbulence model based on Renormalization-Group (RNG) methods is used. This approach applies statistical methods to the derivation of the averaged equations for turbulence quantities, such as turbulent kinetic energy and its dissipation rate.

## 4.2 Subaerial and Submarine Model Similitude

### 4.2.1 Dimensional Analysis

In this part of the thesis, the three different shapes of landslide, circular, rectangular and triangular, are studied.

The aim of this section is to study the wave behavior and the variations of water surface and also the velocity vectors of these three sample slides.

In this word the volumes of these three slides are taken the same, so that they can be compared to each other in order to get accurate results, concerning the variations of initial surface water and initial water waves of landslides.

The purpose of this thesis is to analyze two modelings of rigid and deformable slides. To do so, all three circular, rectangular and triangular slide shapes are considered rigid which remain stable shape while sliding and emerging into water with no deformation. After that these three slide shapes are considered deformable which do not remain stable shape while sliding and emerging into water.

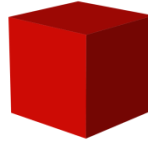
Numerical models were set-up in a 2.5m wide, 1.8m deep and 25m long wave tank with Flow 3D software, and bed slope angle 45 degrees. All of the simulations in this study are performed in three blocks, the shapes of rigid slides have been set up with triangular, rectangular and circular section.

The volume of rectangular block is 3900 cm<sup>3</sup>, triangular block is 3900 cm<sup>3</sup> and circular block is 3900 cm<sup>3</sup>. The density of all the models is 1.9 t/m<sup>3</sup> (Figure 4.1a). Figure 4.1b shows the geometry details of three rigid blocks.



Circular  
Sphere

$V = 3900 \text{ cm}^3$



Rectangular  
Cube

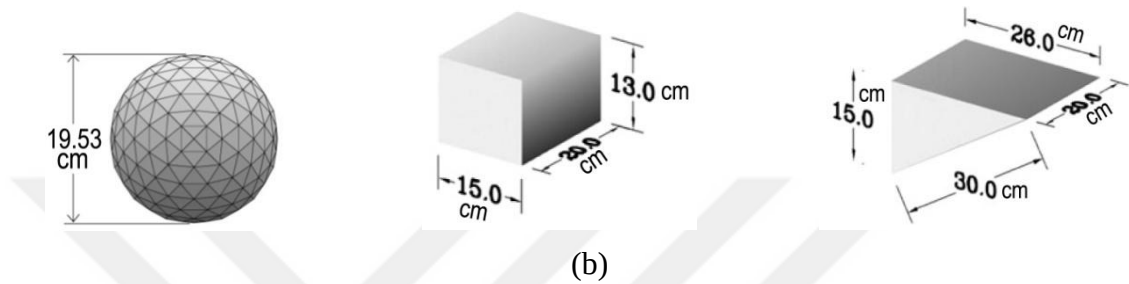
$V = 3900 \text{ cm}^3$



Triangular  
Triangular prism

$V = 3900 \text{ cm}^3$

(a)



(b)

**Figure 4.1 :** (a) Schematic of three rigid blocks, (b) geometry details of three rigid blocks

#### 4.2.2 Mesh Information

Table 4.1 shows some information about the total mesh size and the typical sizes of the grid elements. The number of real cells of X direction is 28 and the minimum and maximum cell sizes of X direction are 8 and 11 cm respectively. Because of the importance and length of the channel, the number of real cells of Y direction is 160 and the minimum and maximum cell sizes of Y direction are 6 and 50 cm respectively.

Also due to the importance and height of the channel and water level, the number of real cells of Z direction is 38 and the minimum and maximum cell sizes of Z direction are 5 and 5 cm respectively. Besides, the total number of real cells are 170000. In this modeling the cpu time spent in each simulation is 40 minutes.

**Table 4.1 :** Grid information for mesh blocks

| Mesh information       | X direction | Y direction | Z direction |
|------------------------|-------------|-------------|-------------|
| Number of real cells   | 28          | 160         | 38          |
| Minimum cell size (cm) | 8           | 6           | 5           |
| Maximum cell size (cm) | 11          | 50          | 5           |

Figure 4.2 shows grid and mesh blocks at the first simulation. Because of the importance of the middle part, the distance between the meshes was reduced and meshes were compressed in the middle part. In this study viscous flow and laminar model are used for simulations (Figure 4.2).

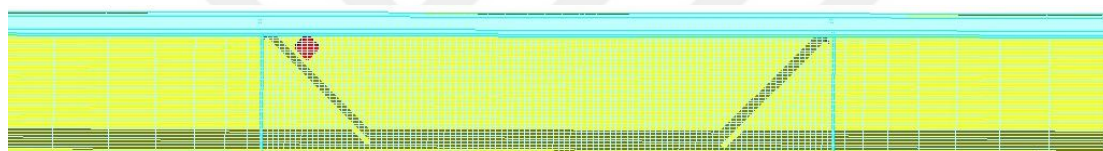


**Figure 4.2 :** View of grid and mesh blocks

### 4.2.3 Subaerial Simulations

#### 4.2.3.1 Introduction

In this study three rigid blocks are used for modeling; hence the shapes of rigid slides have been set up with triangular section, rectangular section and circular section.

First, rectangular slide is analyzed in a channel which is, to have an accurate depiction, cross section sectioned A-A and B-B.

Figure 4.3 shows the top view of numerical models of Flow 3D software. This Figure shows subaerial rectangular rigid slide by red color and two cross sections A-A and B-B.

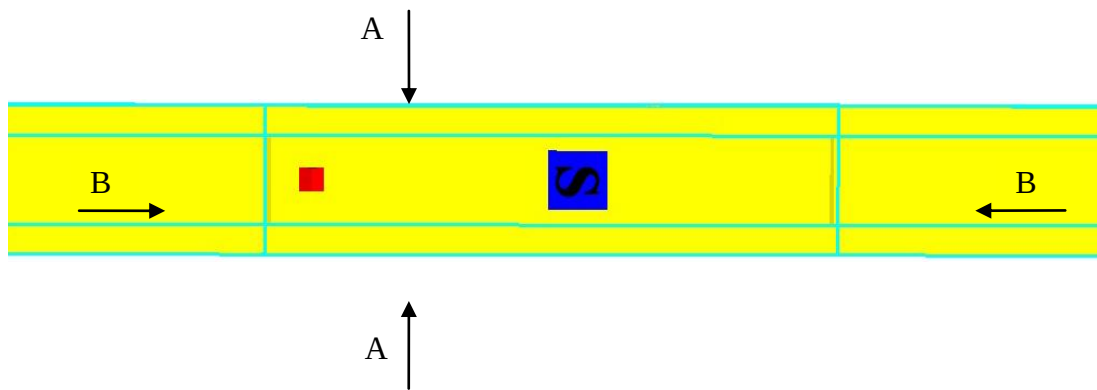


**Figure 4.3 :** Top view of numerical models

To understand this simulation clearly, the channel is shown from several different angles. Figure 4.4 shows the Front view of numerical models of Flow-3D software.

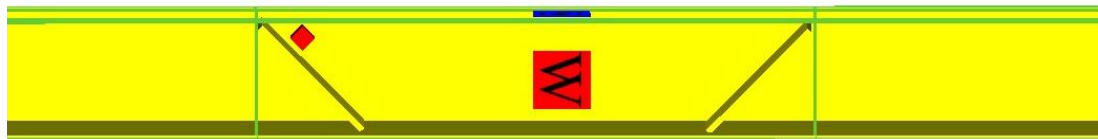


**Figure 4.4 :** Front view of numerical models

In the following figures, the modeling is viewed from different angles to fully determine the status of the rigid slide shape and its placement in the channel.

Figure 4.5 shows the 3D view of numerical model of Flow-3D software.

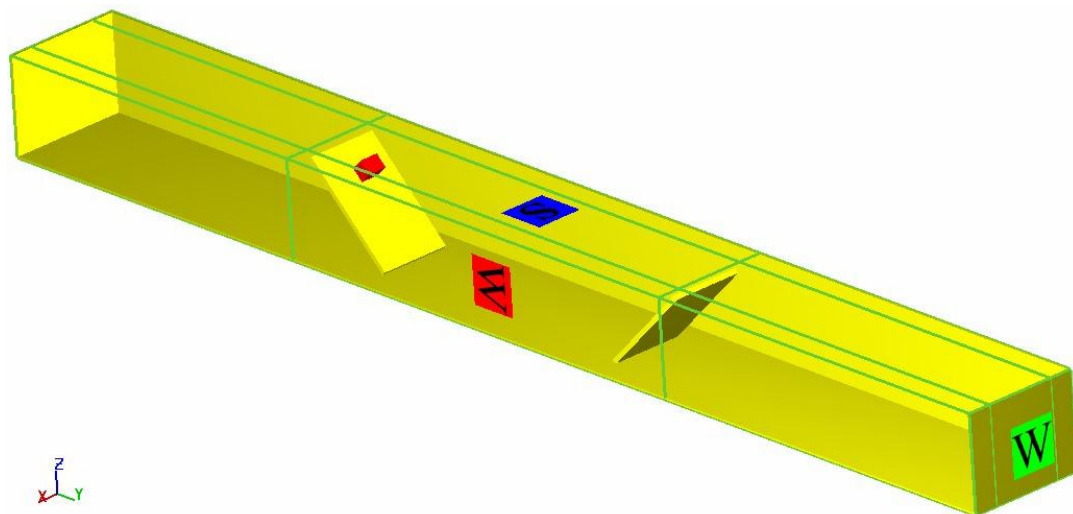


**Figure 4.5 :** 3D view of numerical models

Figure 4.6 shows the Top-Front view of numerical model of Flow-3D software.

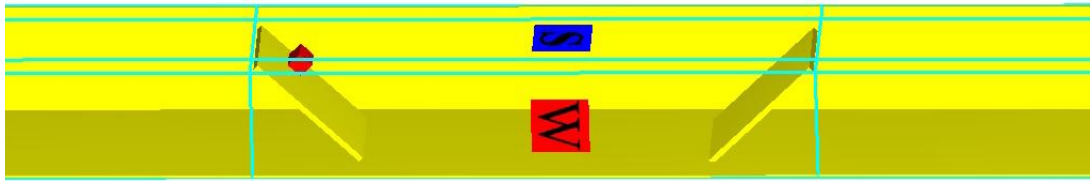


**Figure 4.6 :** Top-Front view of numerical models

Hence in this figure a 3D view of the rigid slide shape and the channel is depicted. The channel features rectangular and there are two angular surfaces with  $45^\circ$ .

In this modeling, using Flow-3D software, the rigid block sides from the top of the angular surface and sinks into the water.

Figure 4.7 shows 3D top view of numerical model full of water.

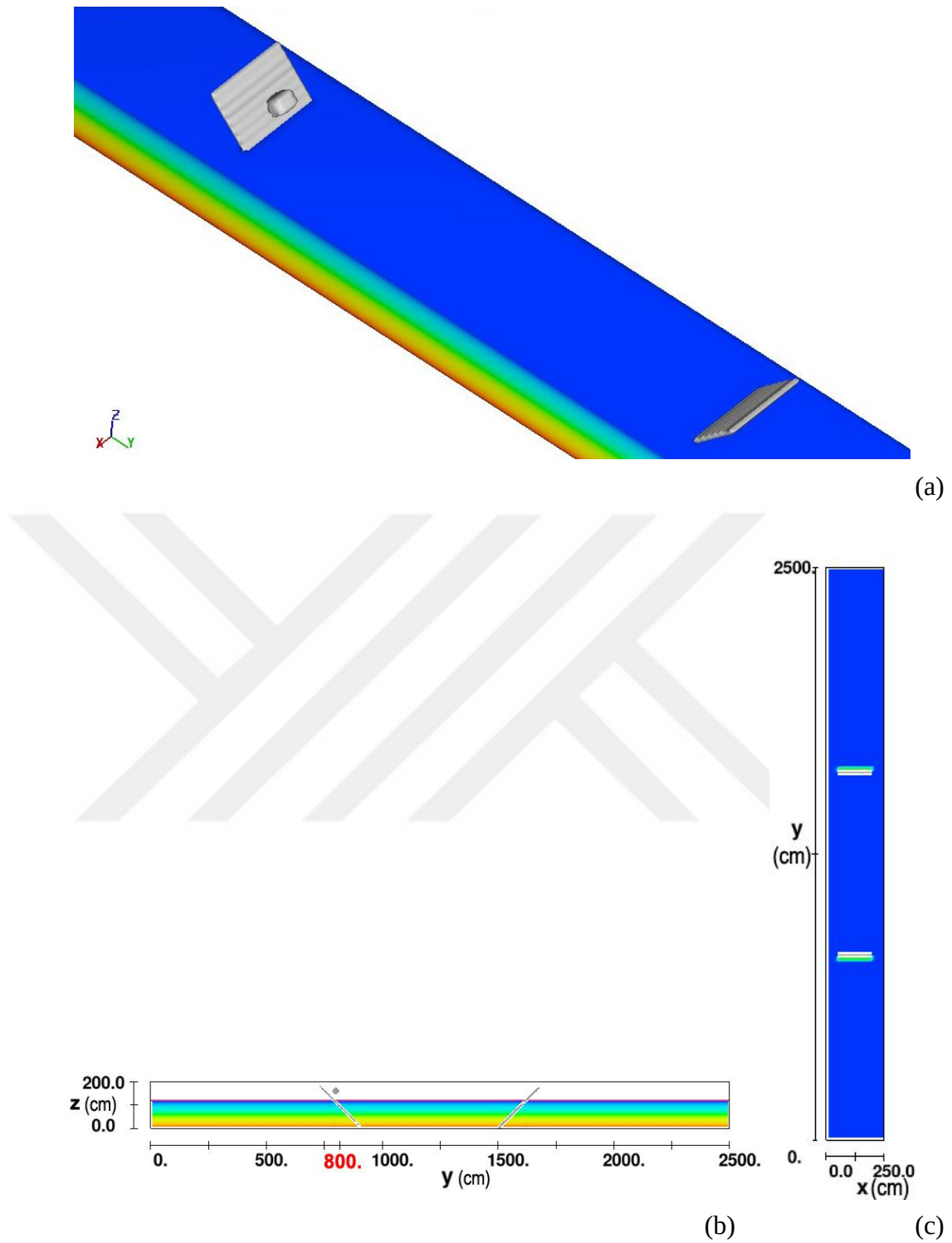


**Figure 4.7 :** (a) 3D Top view of numerical model full of water, (b) view of cross sections B-B, (c) Top view of numerical model

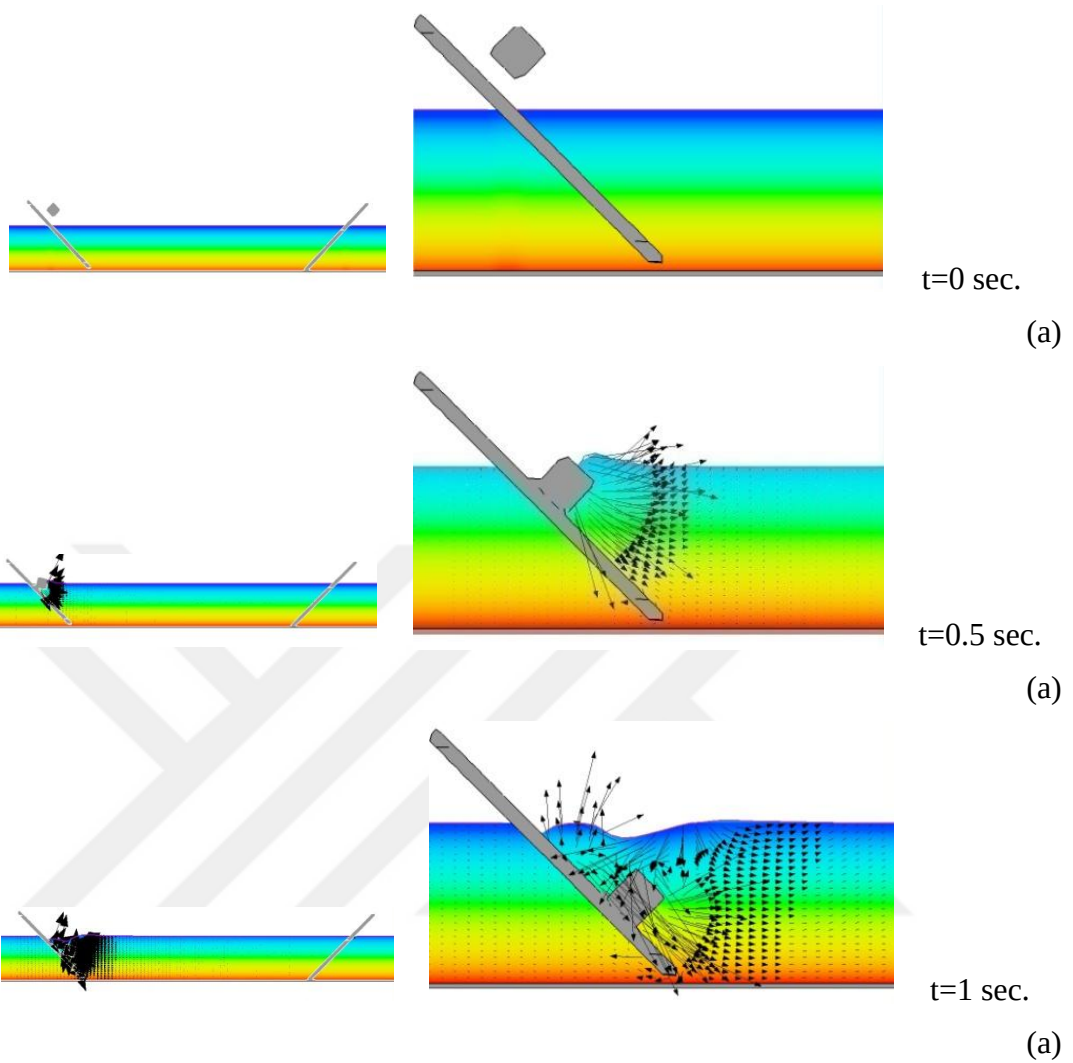
#### 4.2.3.2 Rigid Blocks

Velocity vectors at  $t=0$ ,  $t=0.5$  and  $t=1$  s. for subaerial different landslide geometries ( cross section B-B ) are shown in Figure 4.8.

Figure 4.8 shows the velocity fields of the SPH models at various times. While the rigid body is falling, high pressures are observed at the bottom of left corner of the channel, where the velocity is diminishing, and at the same time flow separation occurs at the bottom of right corner of the moving body as shown in the snapshots at  $t=0.5$  s of Figure 4.8. Subsequently, a large counterclockwise vortex is generated in the front of the moving body. The RANS model results show that the vortex is averted downstream (positive  $x$  direction) with a much slower speed than the phase speed of the generated solitary-like wave. Furthermore, the SPH results indicate that the vortex is attached to the front face of the rigid body until the body reaches the bottom of the channel. This discrepancy in two numerical results needs to be further examined with velocity measurements. As the results show, the pressure near the vortex center is less than the hydrostatic pressure.

This modeling implemented on rectangular rigid slide is carried out on circular and triangular cases under same conditions. As shown in Figure 4.8, the status, direction and amplitude of velocity vectors considering the situation of slide are demonstrated at different times.

Rigid rectangular Landslide:



Rigid triangular Landslide:

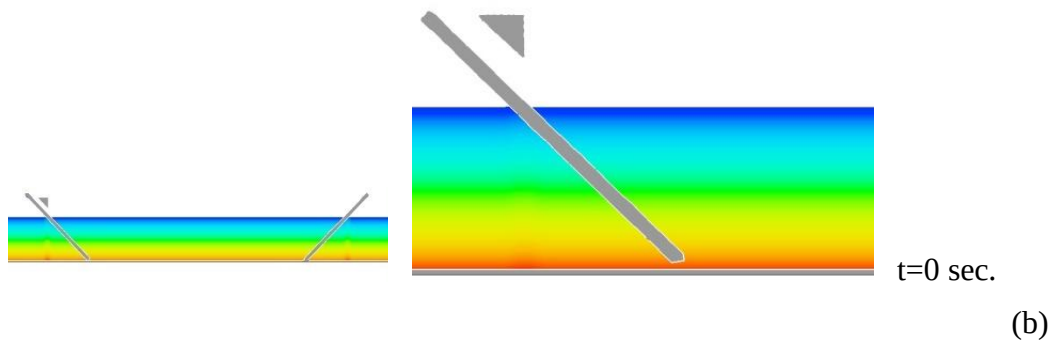
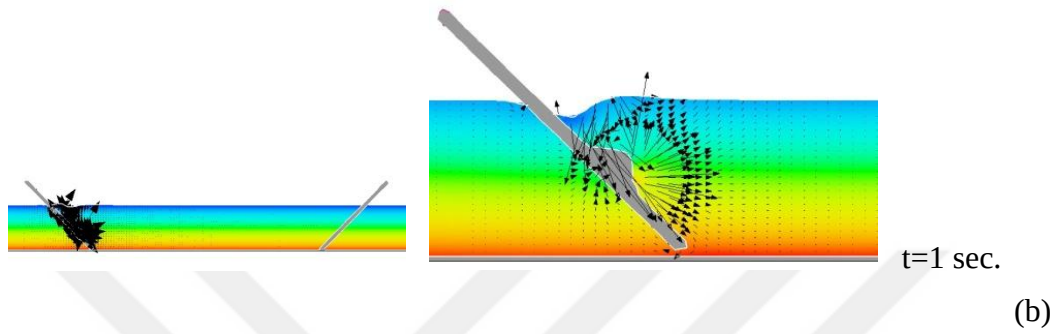
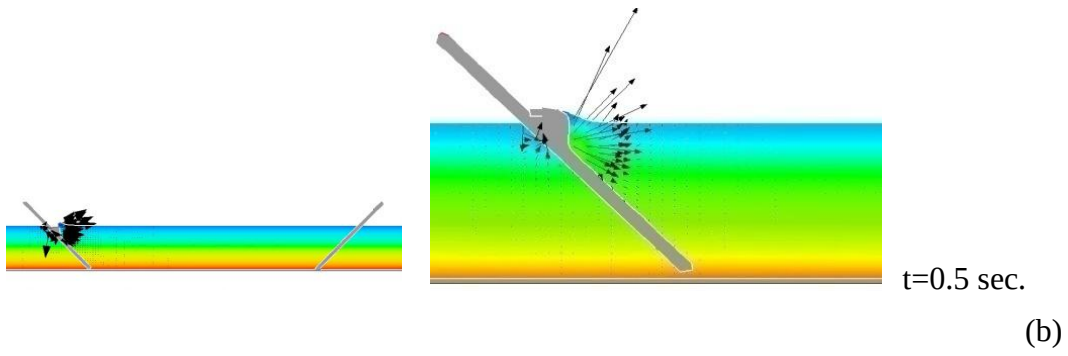


**Figure 4.8 :** Velocity vectors for rigid subaerial different landslide geometries  
(a) Rectangular landslide, (b) Triangular landslide, (c) Circular landslide



Rigid circular landslide:

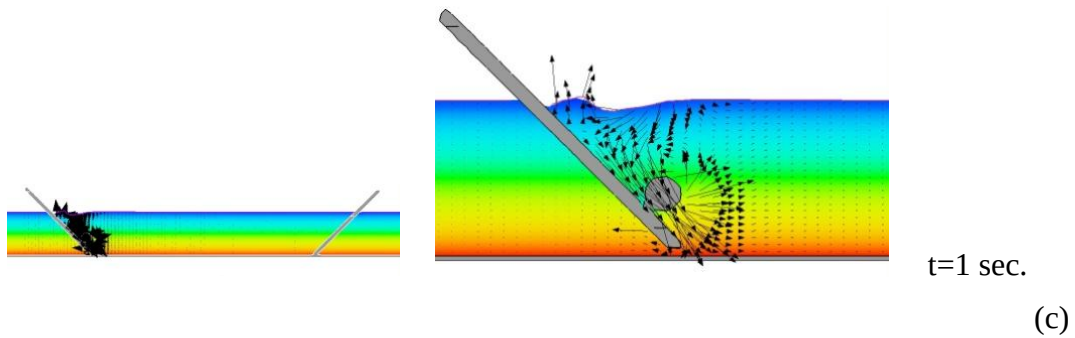
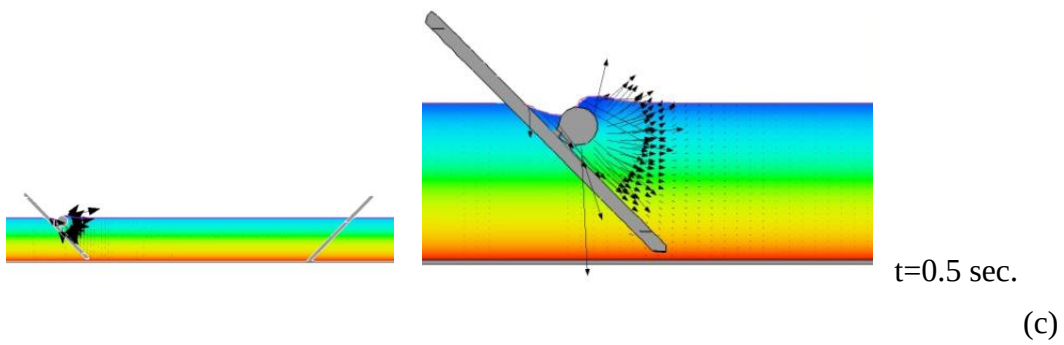
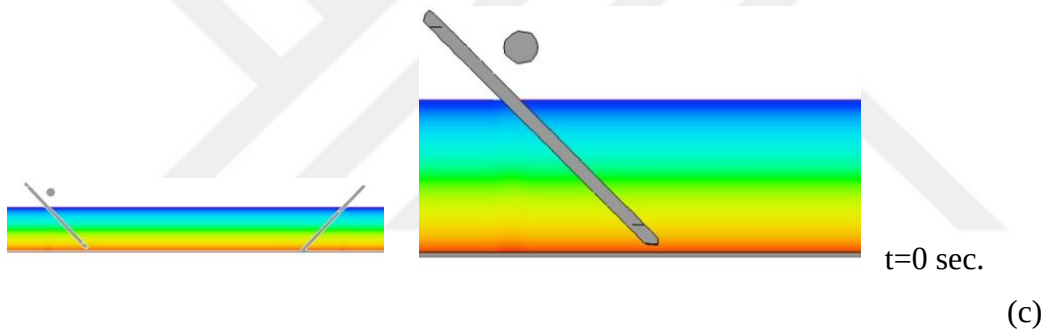


**Figure 4.8 (continued) :** Velocity vectors for rigid subaerial different landslide geometries (a) Rectangular landslide, (b) Triangular landslide, (c) Circular landslide

The numerical results of wave amplitudes over time in locations of  $y=8\text{m}$  (cross section A-A) for different types of landslide geometries are presented in Figure 4.9. It is shown that the wave amplitude has the highest and lowest values in triangular, and circular shapes, respectively.

This analysis shows that the water level has changed lowest in circular sphere, therefore this indicates that the circular shape to create the water waves is less effective than other forms.

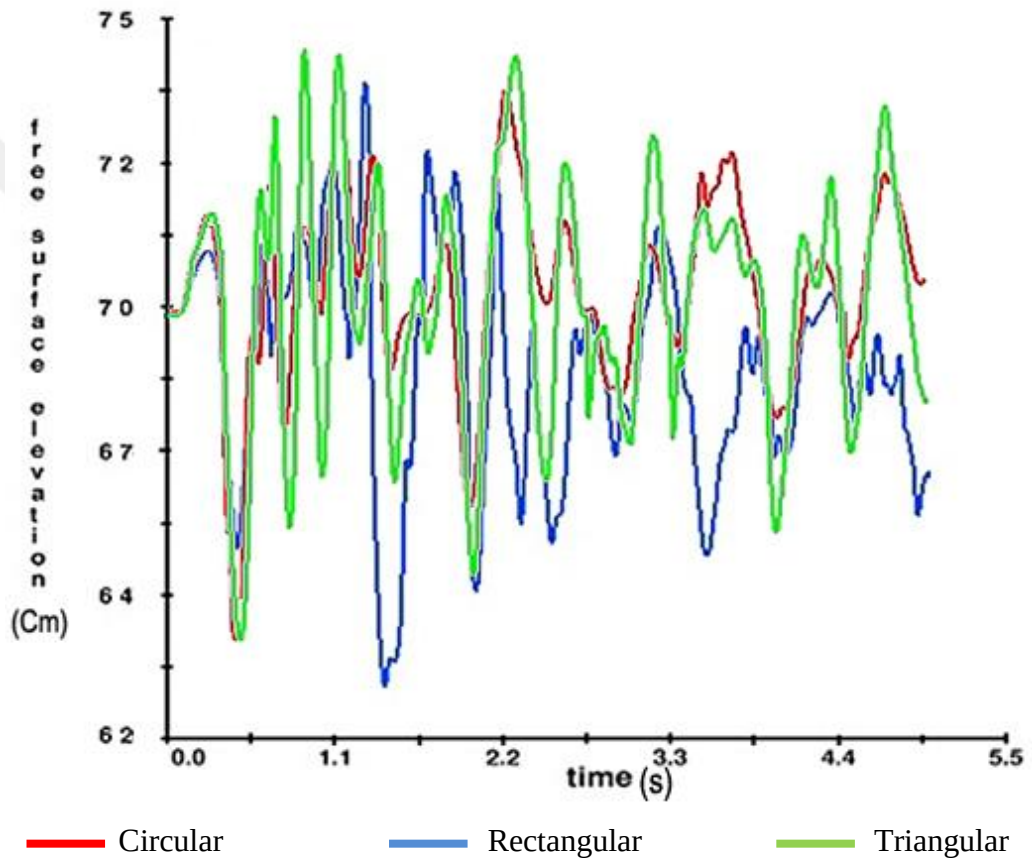


**Figure 4.9 :** Numerically-derived wave amplitudes for different rigide landslide geometries at  $y=8\text{m}$

#### 4.2.3.3 Deformable Blocks

The same modeling implemented in the preceding section is repeated for deformable rectangular slide. This modeling is simulated and analyzed by Flow 3D software. Afterwards, the results obtained from velocity vectors at cross section B-B are compared at different times.

Velocity vectors at  $t=0$ ,  $t=0.5$  and  $t=1$  second. For subaerial deformable rectangular landslide geometry ( cross section B-B) are shown in Figure 4.10.

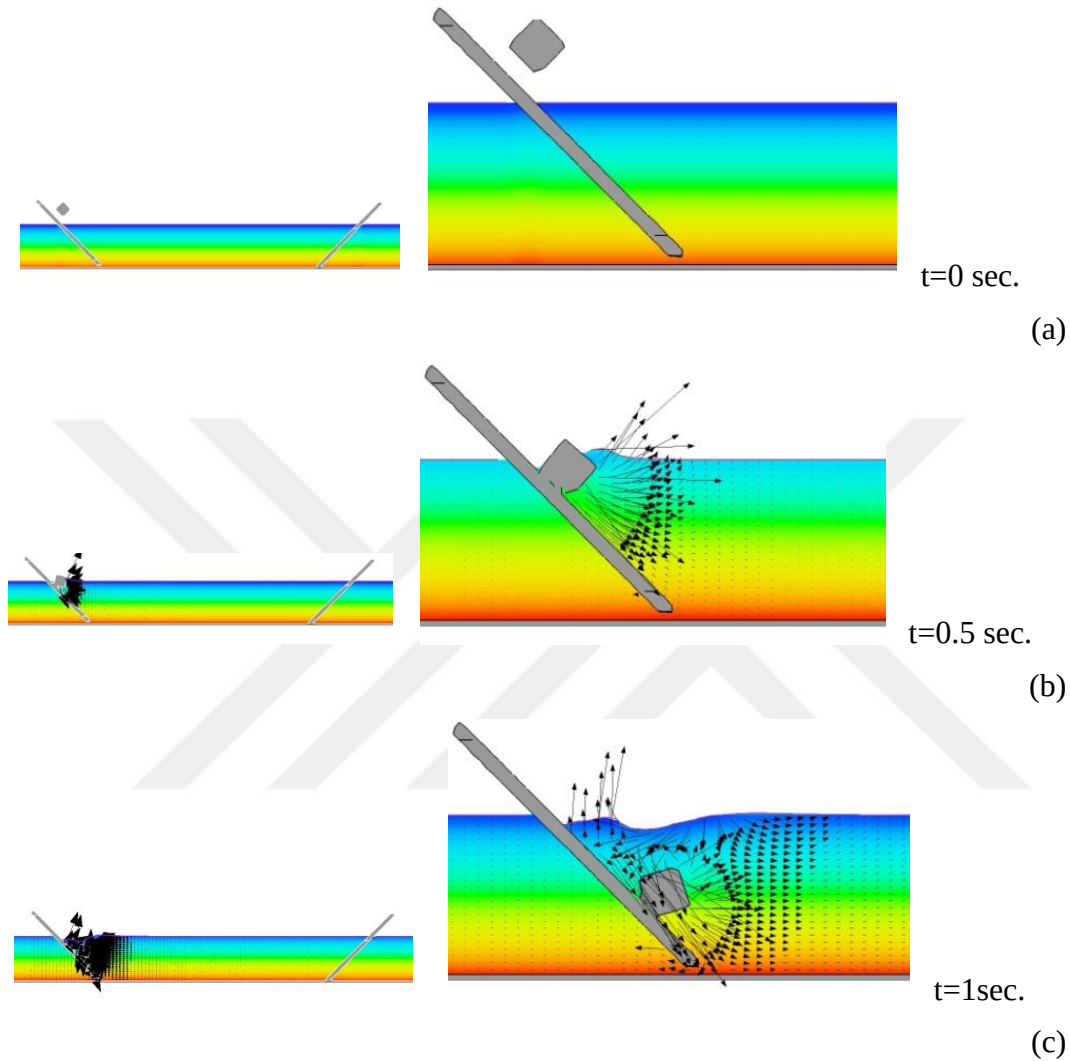


**Figure 4.10 :** Velocity vectors for subaerial deformable rectangular landslide geometry: (a)  $t=0$  sec., (b)  $t=0.5$  sec., (c)  $t=1$  sec.

It can be recognized that the hydraulic parameters at two status, rigid and deformable rectangular, are similar; Only a little differs in the variations of initial water surface.

#### 4.2.4 Submarine Simulations

##### 4.2.4.1 Rigid Blocks

Velocity vectors at  $t=0$ ,  $t=0.5$  and  $t=1$  s. for submarine rigid rectangular landslide geometry are shown in Figure 4.11.

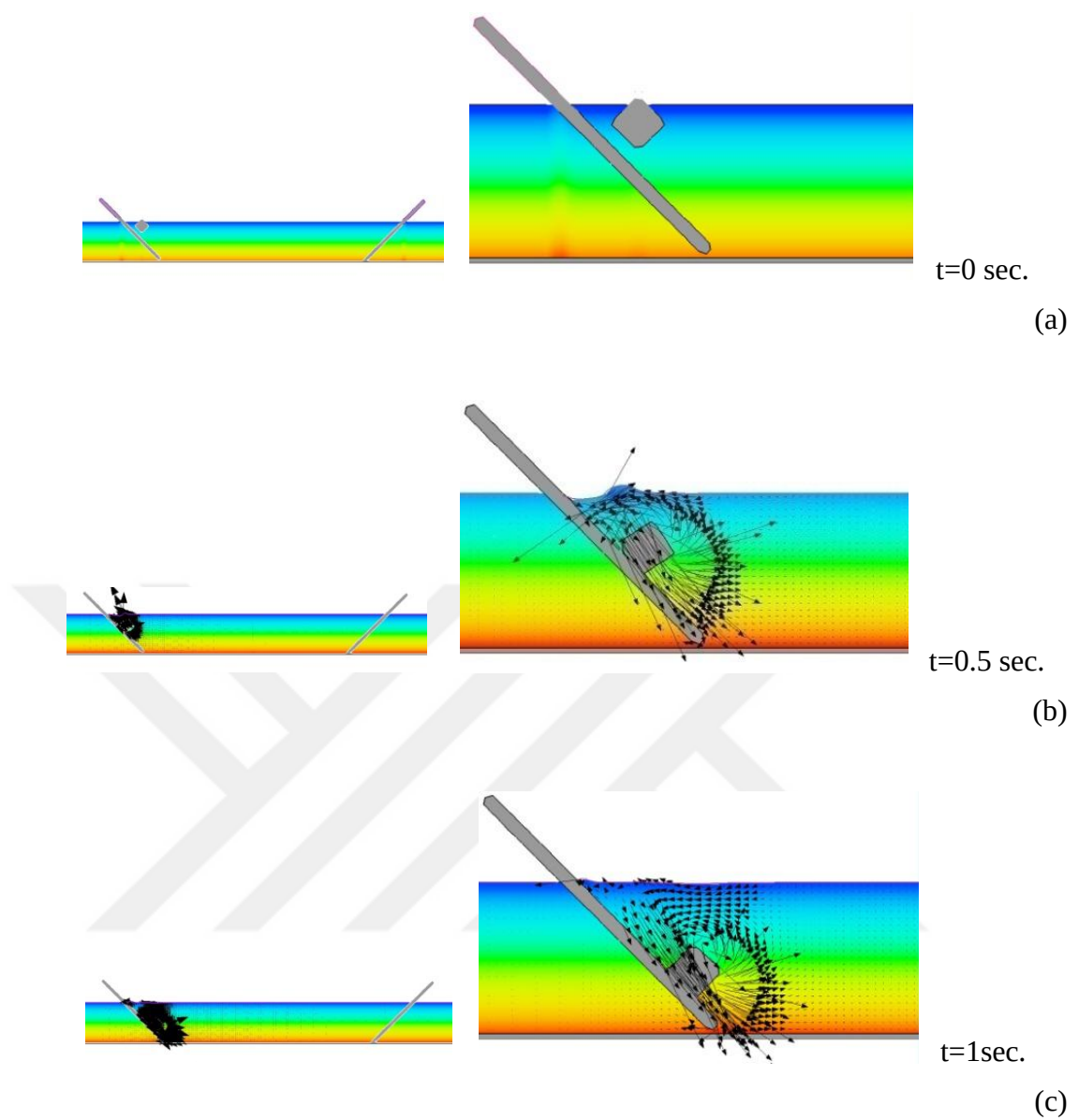


**Figure 4.11** : Velocity vectors for submarine rigid rectangular landslide geometry:  
(a)  $t=0$  sec., (b)  $t=0.5$  sec., (c)  $t=1$  sec.

#### 4.2.4.2 Deformable Blocks

Velocity vectors at  $t=0$ ,  $t=0.5$  and  $t=1$  s. for submarine deformable rectangular landslide geometry are shown in Figure 4.12.

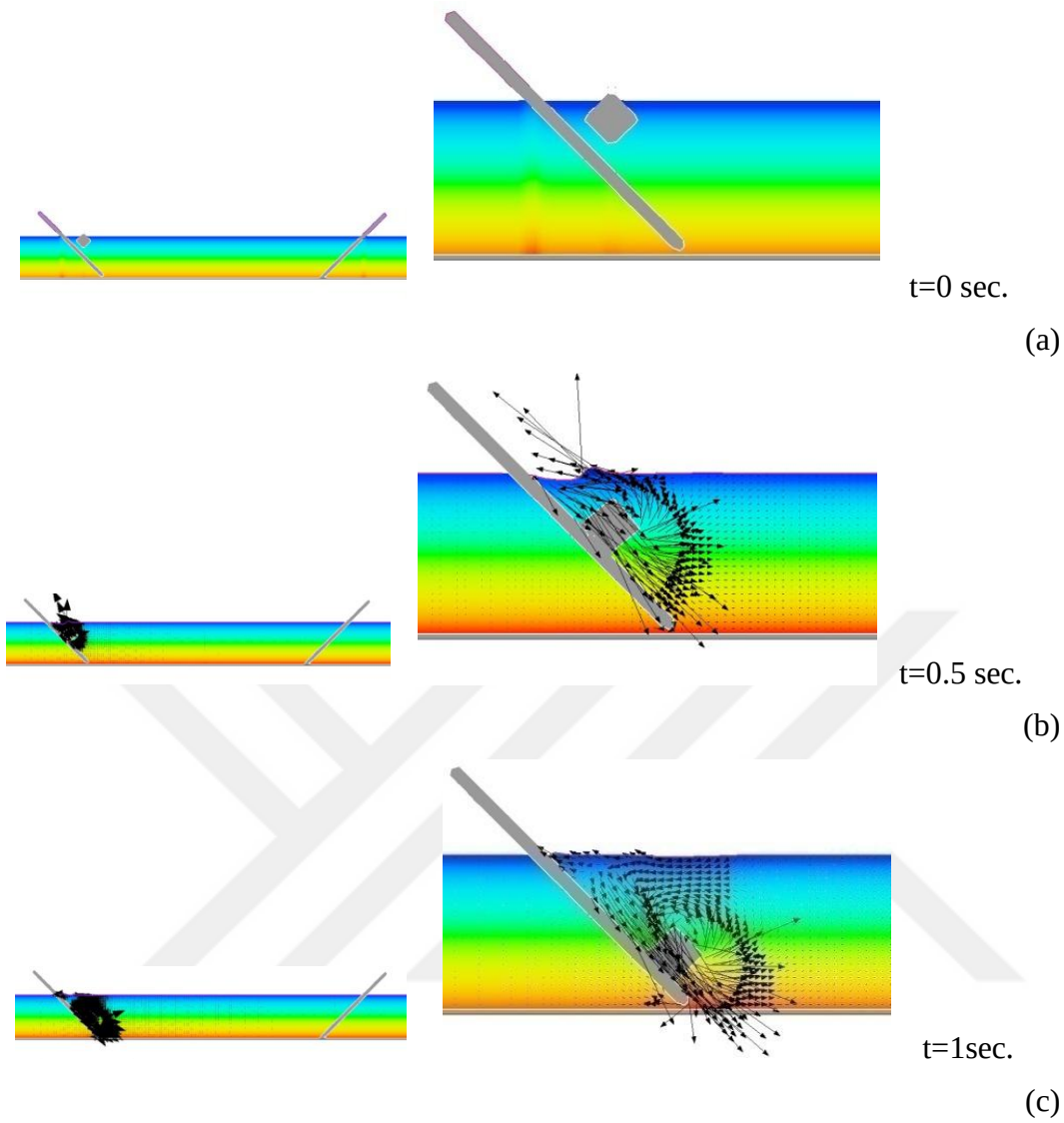


**Figure 4.12 :** Velocity vectors for submarine deformable rectangular landslide geometry: (a)  $t=0$  sec., (b)  $t=0.5$  sec., (c)  $t=1$  sec.

The time series of the free surface elevation at  $y=8$  m for submarine deformable rectangular landslide geometry and submarine rigid rectangular landslide geometry are shown in figure 4.13.

The generated wave is a solitary-like wave with small trailing waves. The calculated maximum and minimum wave heights at both situations show the difference of deformable and rigid rectangular geometries. However, figure 4.13 shows a slight phase difference together. Thus, the deformable and rigid shapes change the generated wave less than 9%.

Table 4.2 shows the variations of water surface elevation (wave) for submarine deformable rectangular landslide geometry and submarine rigid rectangular landslide geometry obtained from Flow-3D models for 10 seconds.

The maximum and minimum levels of water (wave heights) for submarine rigid rectangular landslide geometry are 121.0 and 118.5 cm respectively, so the water level changes 2.5 cm. On the other hand, the maximum and minimum levels of water (wave heights) for submarine deformable rectangular landslide geometry are 120.4 and 119.0 cm respectively, so the water level changes 1.4 cm.

**Table 4.2 :** Variations of water surface elevation (wave) for submarine deformable rectangular landslide geometry and submarine rigid rectangular landslide geometry obtained from Flow-3D models for 10 s.

| Time (s)                                             | 0     | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
|------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Water Surface Elevation (cm)<br>Rigid landslide      | 120.0 | 118.5 | 121.0 | 119.3 | 120.3 | 120.2 | 119.9 | 119.7 | 119.6 | 120.4 | 120.0 |
| Water Surface Elevation (cm)<br>Deformable landslide | 120.0 | 119.0 | 120.4 | 119.5 | 120.1 | 120.3 | 120.3 | 119.6 | 119.5 | 120.3 | 119.9 |

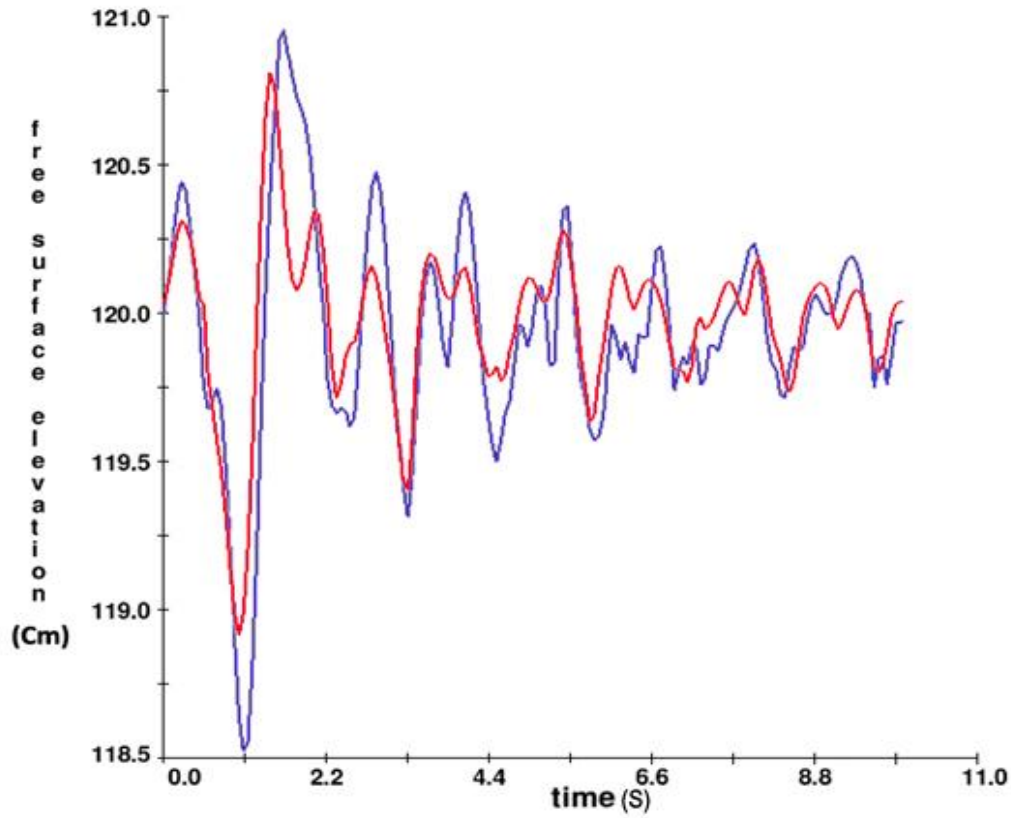


**Figure 4.13 :** Time histories of free surface elevation at  $y=8$  m obtained from Flow-3D models.

Red line : submarine deformable rectangular landslide geometry

Blue line : submarine rigid rectangular landslide geometry

The time series of mean kinetic energy for submarine deformable rectangular landslide geometry and submarine rigid rectangular landslide geometry are shown in figure 4.14.

The numerical results of mean kinetic energy over time in locations of  $y=7$  m for submarine deformable rectangular landslide geometry and submarine rigid rectangular landslide geometry are shown in figure 4.14.

It is shown that the maximum mean kinetic energy has the highest and lowest values in rigid and deformable rectangular landslide geometry, respectively.

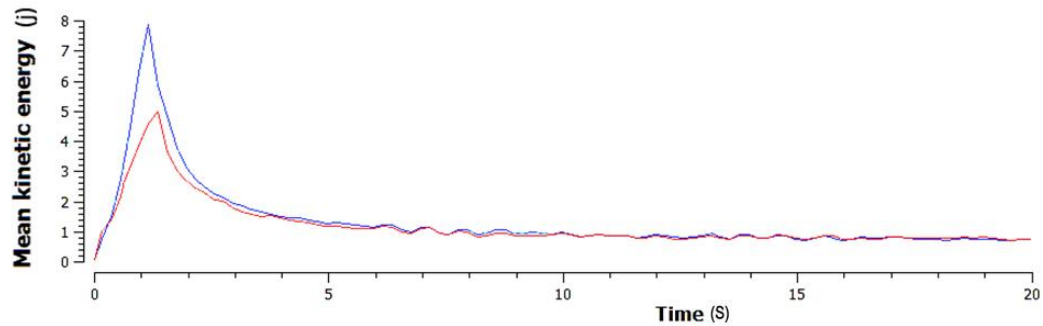


**Figure 4.14 :** Time histories of mean kinetic energy obtained from Flow-3D models.

Red line : Deformable rectangular landslide geometry

Blue line : Rigid rectangular landslide geometry

The initial shape of the granular or deformable slide was similar to the circular section as circular rigid block case. This similarity defines the comparison between the experimental results corresponding to rigid and deformable slide tests with the same initial geometry.

### 4.3 Granular and Rigid Material Simulation

#### 4.3.1 Dimensional Analysis

The numerical models were set-up in a 2.5m wide, 1.8m deep and 25m long wave tank with Flow 3D software; and bed slope angle is 45 degrees. The shape of granular slide and rigid has set up with circular section (Figure 4.15).

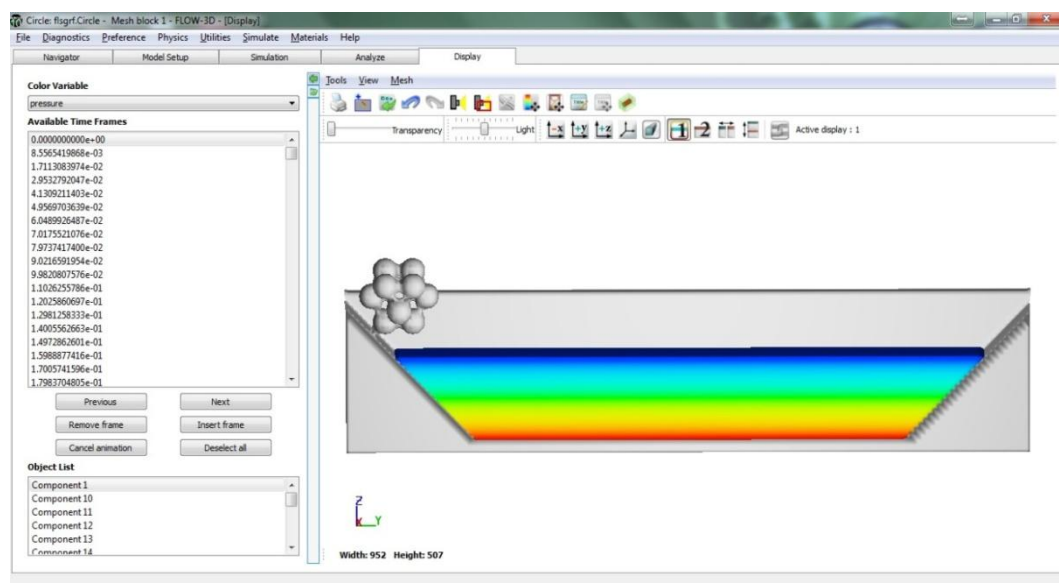


**Figure 4.15 :** View of granular material landslide at Flow 3D software

### 4.3.2 Mesh Information

Table 4.3 shows some information about the total mesh size and the typical sizes of the grid elements. The number of real cells in X direction is 33 and the minimum and maximum cell sizes in X direction are 5 and 10 cm respectively. Because of the importance and length of the channel, the number of real cells in Y direction is 150 and the minimum and maximum cell sizes in Y direction are 5 and 40 cm respectively.

Because of the importance and height of the channel and water level, number of real cells in Z direction are 45 and the minimum and maximum cell sizes in Z direction are 3 and 3 cm respectively. Also total number of real cell is 223000. In this modeling the cpu time spent in each simulation is 60 minutes.

**Table 4.3 :** Grid information for mesh blocks

| Mesh information       | X direction | Y direction | Z direction |
|------------------------|-------------|-------------|-------------|
| Number of real cells   | 33          | 150         | 45          |
| Minimum cell size (cm) | 5           | 5           | 3           |
| Maximum cell size (cm) | 10          | 40          | 3           |

### 4.3.3 Granular Material Simulation

As depicted in Figure 4.16, small granular slides in the implemented modeling gather together and form a circular shape.

The volume of small granular slides are 8200 cm<sup>3</sup>. The density of the models is 1.9t/m<sup>3</sup> (Figure 4.15). Figure 4.16 shows the details of granular material.

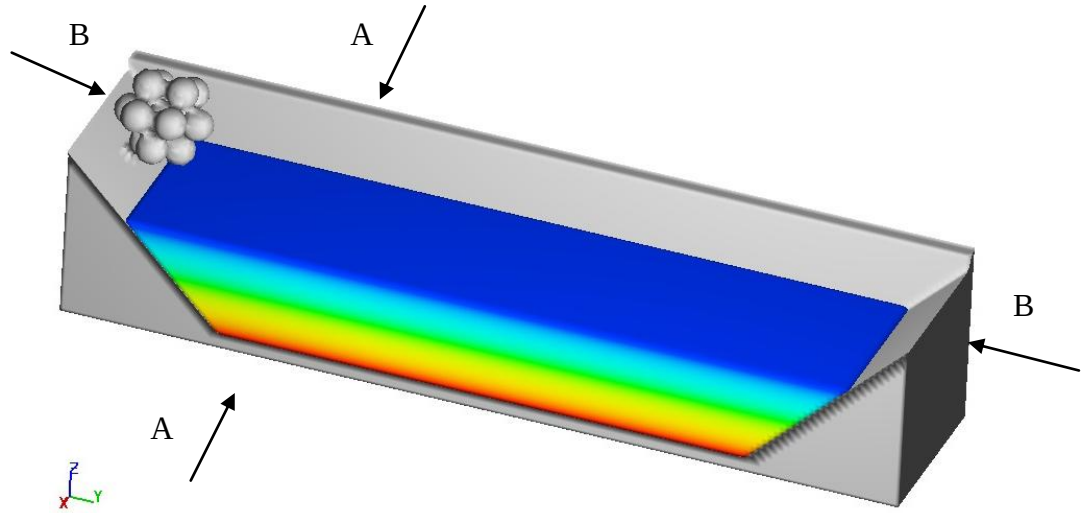


**Figure 4.16 :** 3D view of landslide at Flow 3D software

Figure 4.17 shows the velocity fields of the SPH models at various times. This figure shows the velocity vectors (cross section B-B)

As shown in Figure 4.17, these granular slides at  $t=0$  second are rigid and consistent but after being released, they lose their consistency and yield different slides.

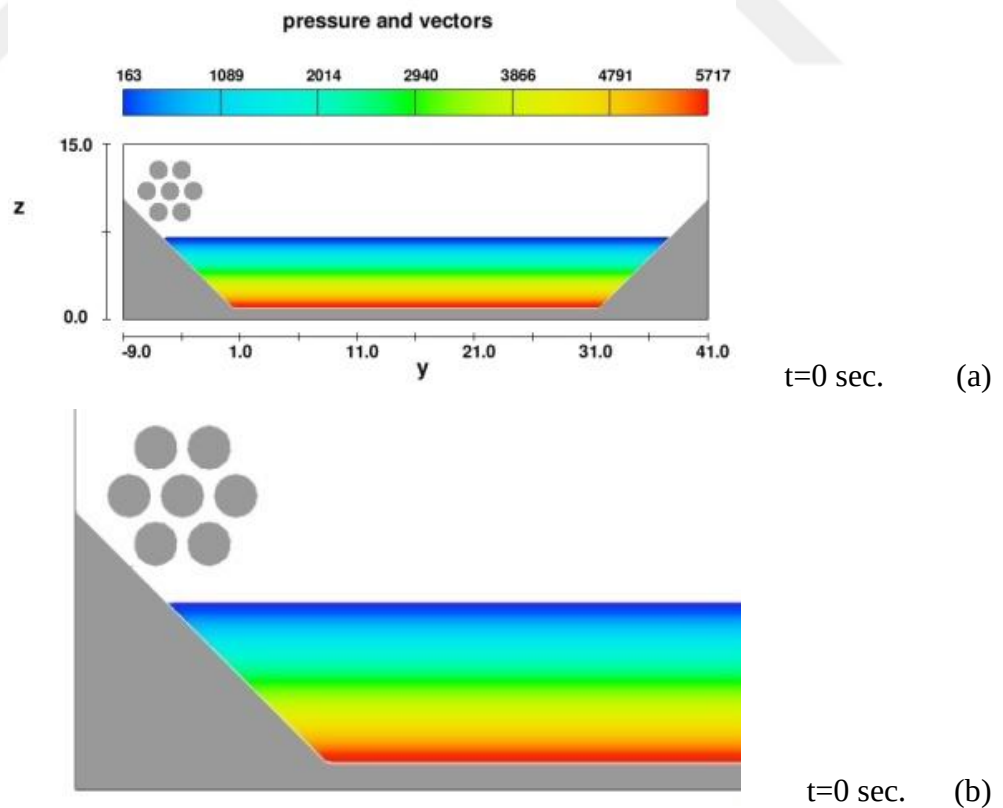


**Figure 4.17 :** Velocity vectors for granular landslide (cross section B-B: (a)  $t=0$  sec., (b)  $t=0$  sec. in more details, (c)  $t=1$  sec., (d)  $t=1$  sec. in more details, (e)  $t=2$  sec., (f)  $t=2$  sec. in more details

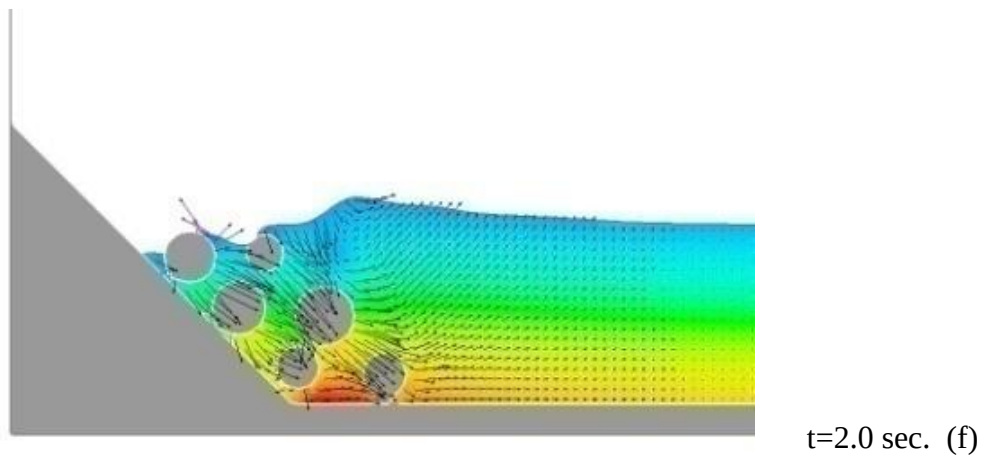
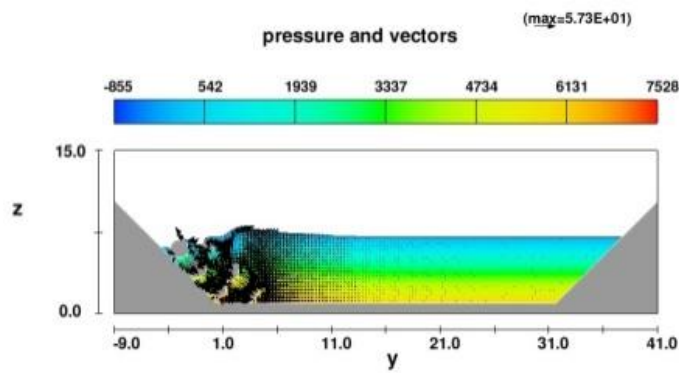
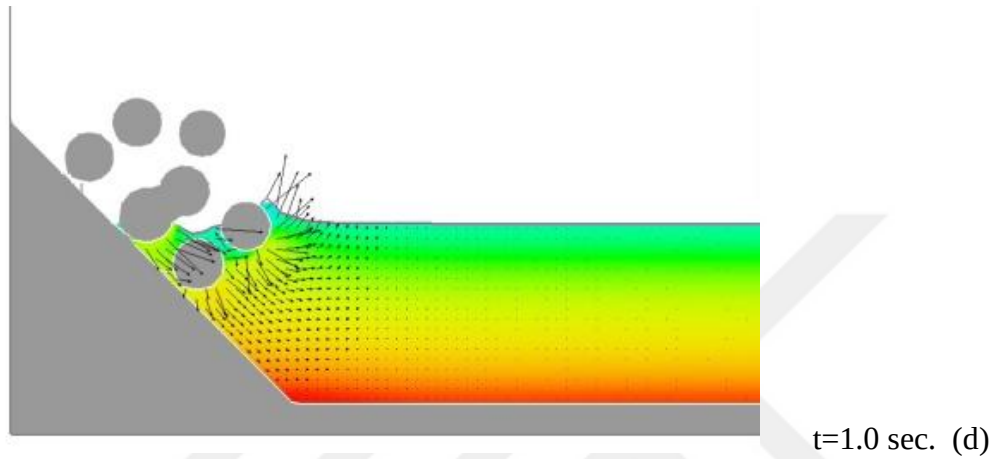
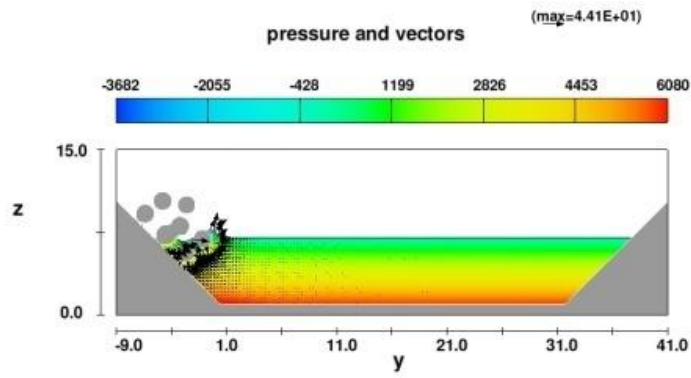


**Figure 4.17 (continued) :** Velocity vectors for granular landslide (cross section B-B): (a) t=0 sec., (b) t=0 sec. in more details, (c) t=1 sec., (d) t=1 sec. in more details, (e) t=2 sec., (f) t=2 sec. in more details

The numerical results of wave amplitudes over time in locations of  $y=7\text{m}$  (cross section A-A) for deformable granular landslide geometry are presented in Figure 4.18. This figure shows the wave amplitude in deformable granular shape.

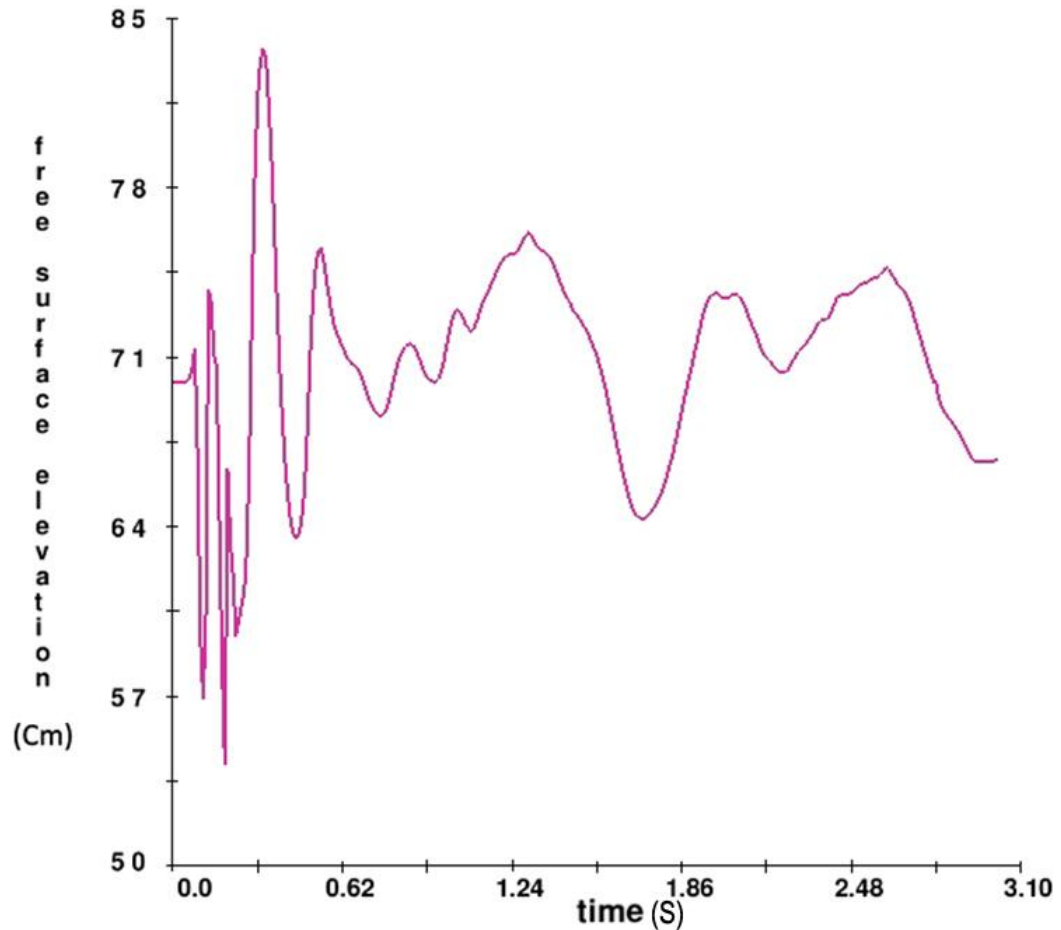


**Figure 4.18 :** Numerically-derived wave amplitudes for deformable granular landslide at  $y=7\text{m}$  (cross section A-A) for 3 seconds

The numerical results of wave amplitudes over time in locations of  $y=7\text{m}$  (cross section A-A) for subaerial landslide are presented in Figure 4.19. This figure shows the wave amplitude and time histories of free surface elevation for 20 seconds.

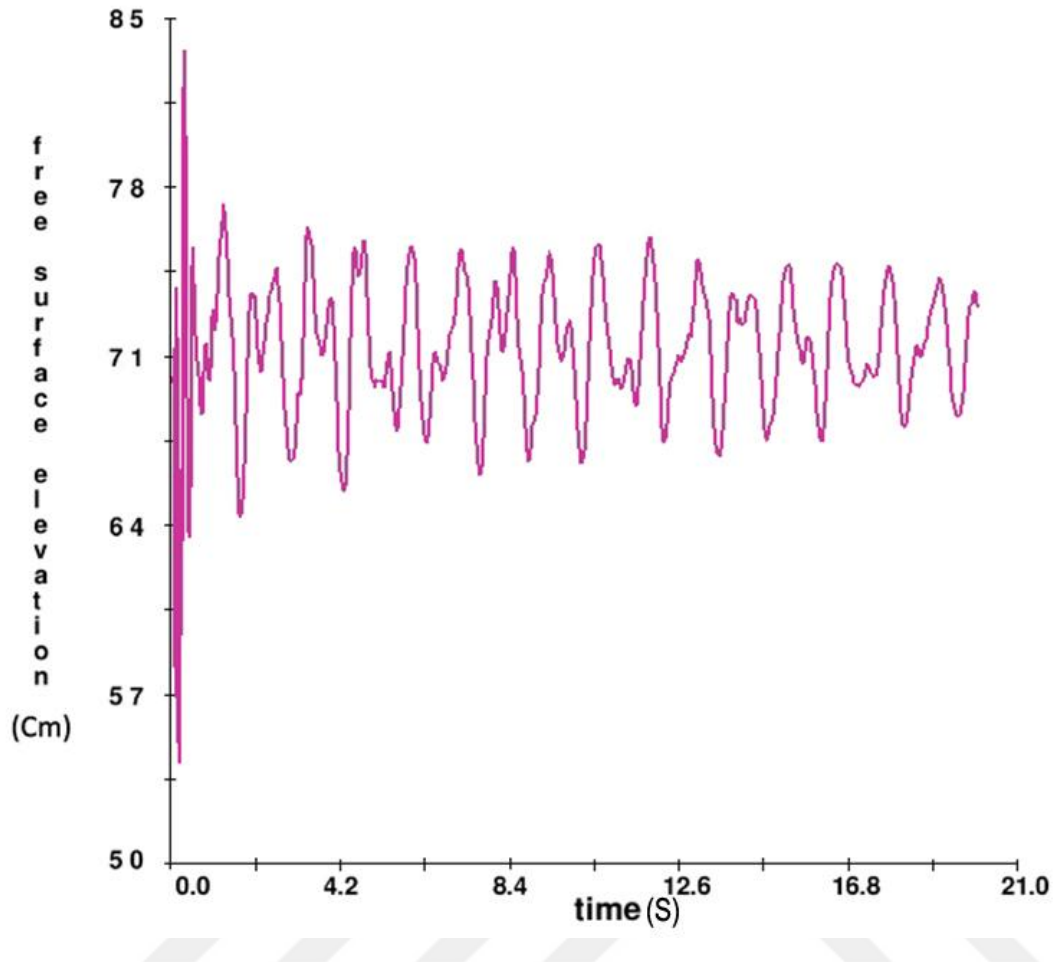


**Figure 4.19 :** Numerically-derived wave amplitudes for deformable granular landslide at  $y=7\text{m}$  (cross section A-A) for 20 seconds

#### 4.3.4 Non-Granular Material Simulation

The volume of non-granular slide is  $8200 \text{ cm}^3$ . The density of the model is  $1.9\text{t/m}^3$  (Figure 4.20).

This modeling is also carried out on the slide which retain that rigidity after being released into water.

Through this modeling, it is viewed that the height of the initial water wave in rigid shape (non-granular) is higher than that of granular shape.

Figure 4.20, shows the geometry details of non-granular material.

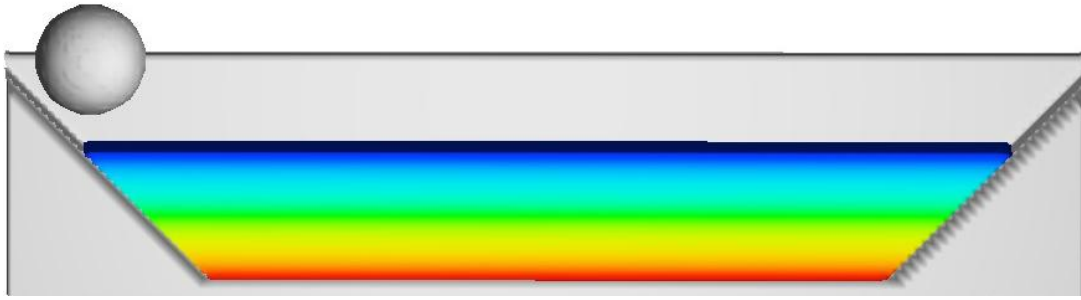


**Figure 4.20 :** View of non-granular material landslide at Flow 3D software

Figure 4.21 shows grid and mesh blocks at the first simulation. Because of the importance of the middle part, the distance between the meshes was reduced and meshes are compressed in the middle part (Figure 4.21).

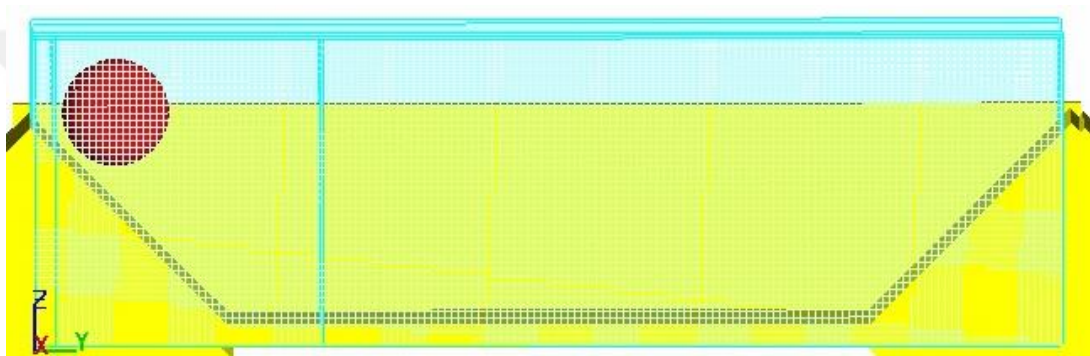


**Figure 4.21 :** View of mesh details of non-granular material landslide at Flow-3D software

Figure 4.22 shows 3D top view of numerical non-granular model full of water.

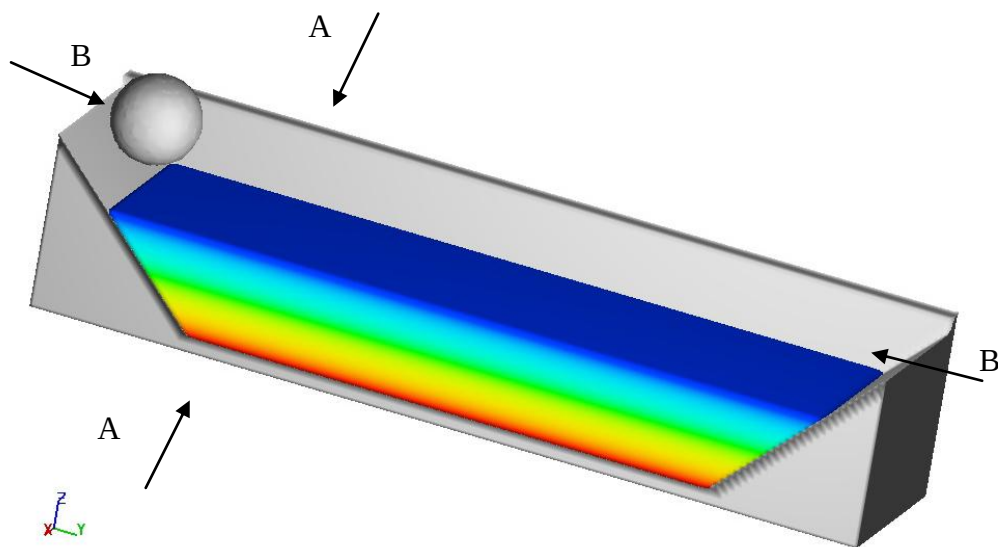


**Figure 4.22 :** 3D view of landslide at Flow 3D software

Figure 4.23 shows the velocity fields of the SPH models at various times. This figure shows the velocity vectors (cross section B-B)

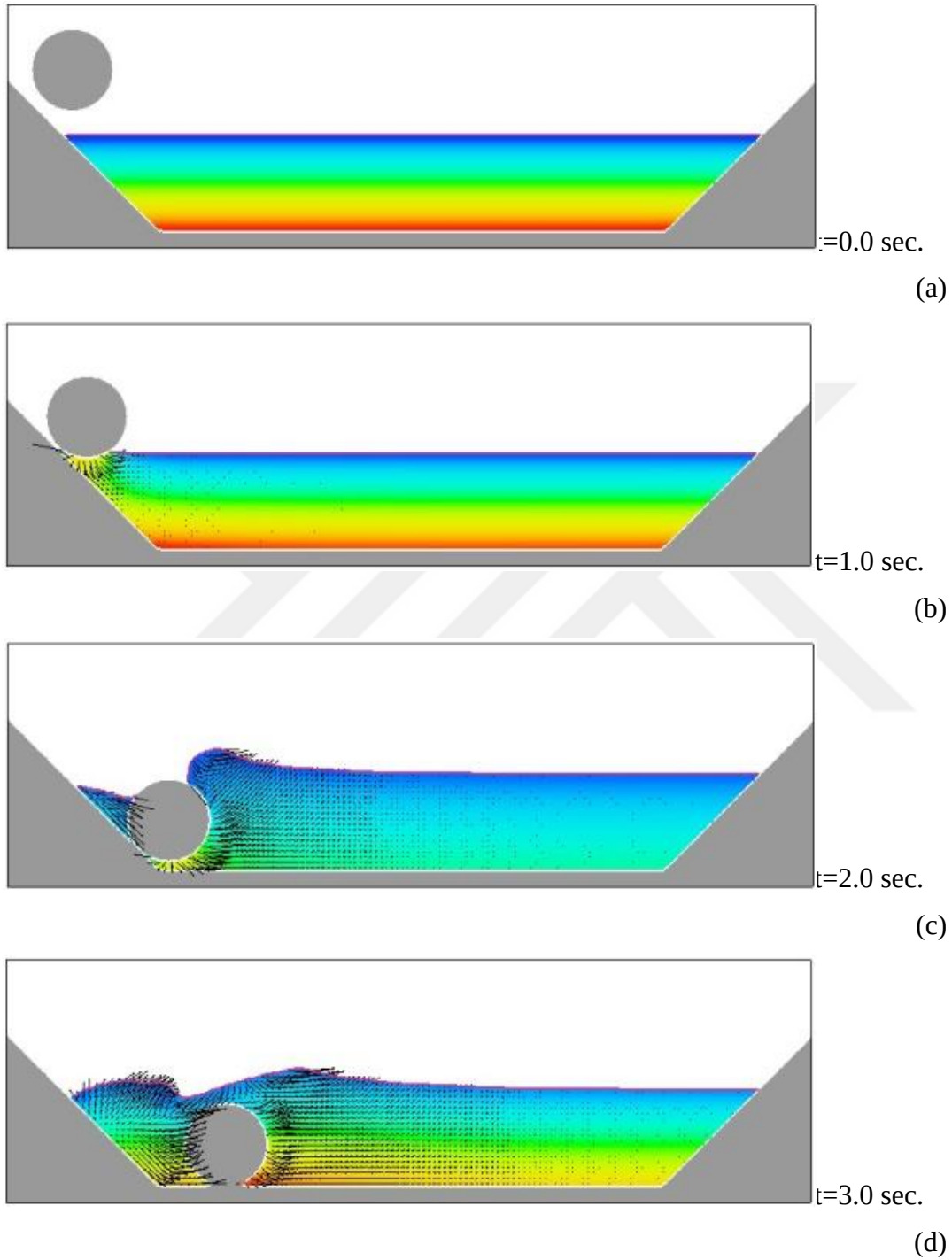
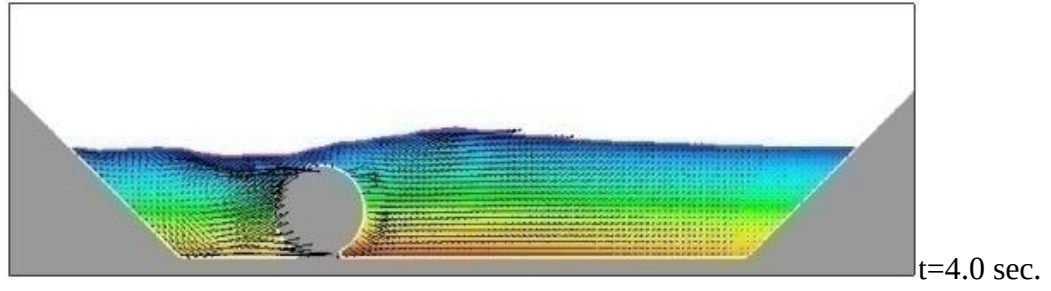
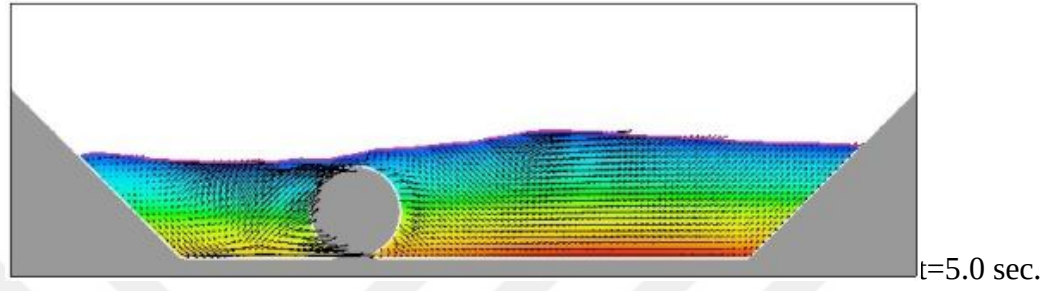


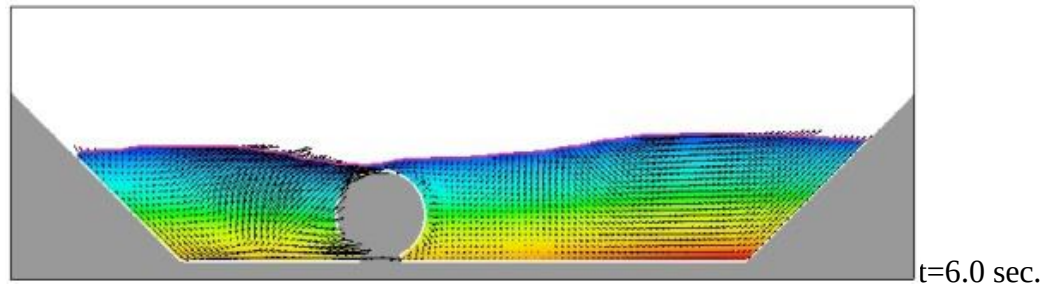
**Figure 4.23 :** Velocity vectors for non-granular landslide (cross section B-B): (a)  $t=0.0$  sec., (b)  $t=1.0$  sec., (c)  $t=2.0$  sec., (d)  $t=3.0$  sec., (e)  $t=4.0$  sec., (f)  $t=5.0$  sec., (g)  $t=6.0$  sec., (h)  $t=7.0$  sec., (i)  $t=8.0$  sec., (j)  $t=9.0$  sec., (k)  $t=10.0$  sec.



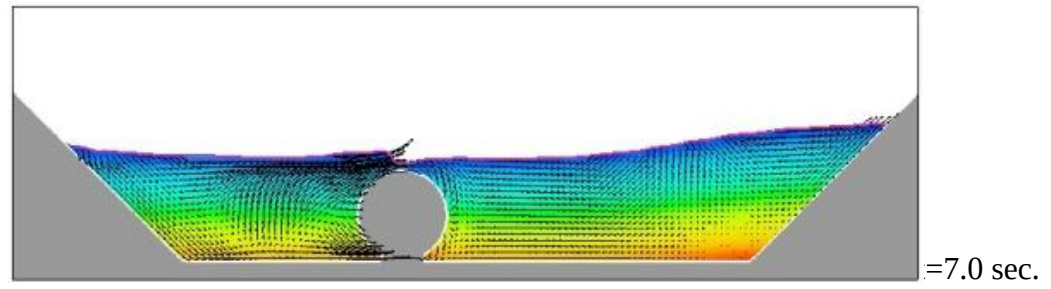
(e)



(f)



(g)



(h)

**Figure 4.23 (continued) :** Velocity vectors for non-granular landslide (cross section B-B) : (a) t=0.0 sec., (b) t=1.0 sec., (c) t=2.0 sec., (d) t=3.0 sec., (e) t=4.0 sec., (f) t=5.0 sec., (g) t=6.0 sec., (h) t=7.0 sec., (i) t=8.0 sec., (j) t=9.0 sec., (k) t=10.0 sec.

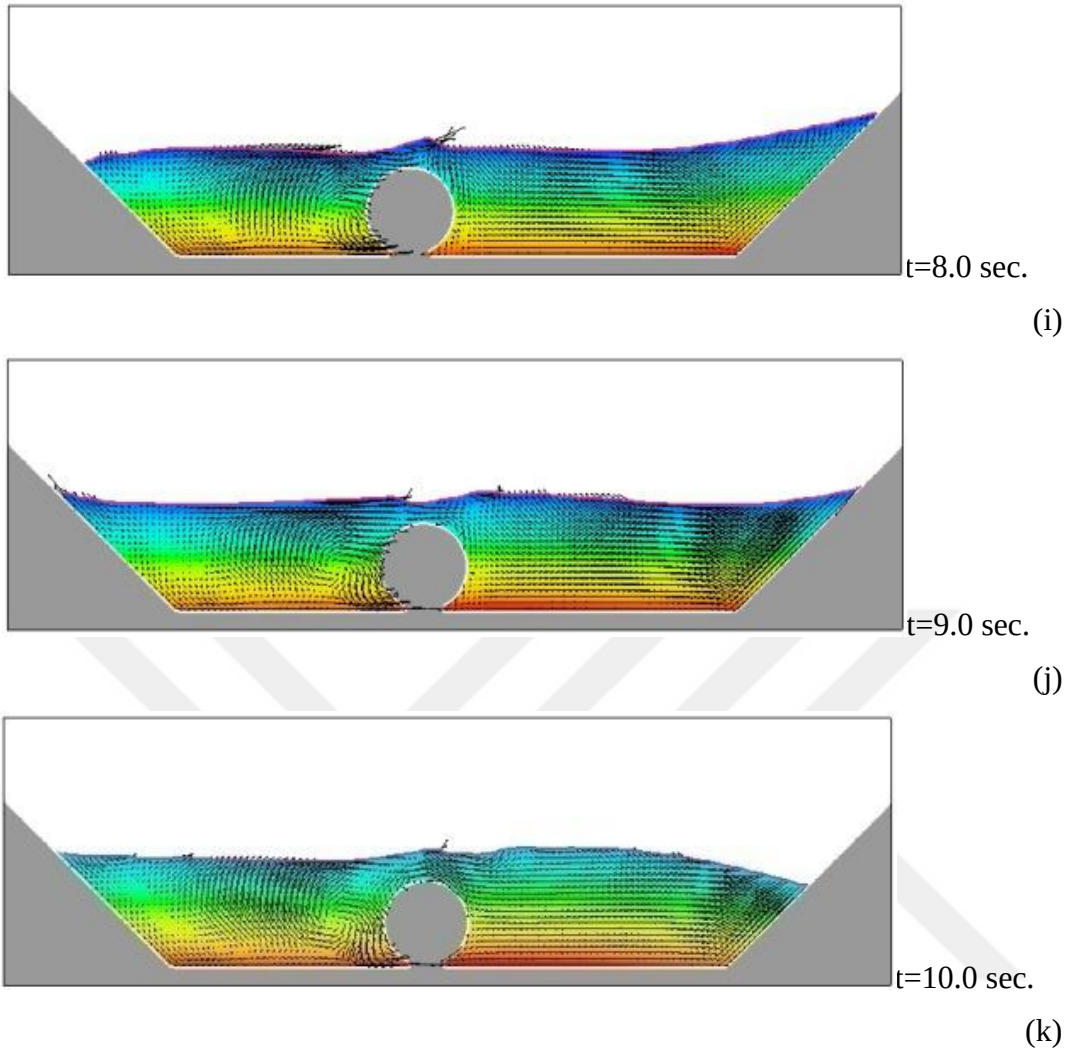


**Figure 4.23 (continued) :** Velocity vectors for non-granular landslide (cross section B-B): (a)  $t=0.0$  sec., (b)  $t=1.0$  sec., (c)  $t=2.0$  sec., (d)  $t=3.0$  sec., (e)  $t=4.0$  sec., (f)  $t=5.0$  sec., (g)  $t=6.0$  sec., (h)  $t=7.0$  sec., (i)  $t=8.0$  sec., (j)  $t=9.0$  sec., (k)  $t=10.0$  sec.

The numerical results of wave amplitudes over time at locations of  $y=7\text{m}$  (cross section A-A) for non- granular landslide geometry are presented in Figure 4.24. This figure shows the wave amplitude in non- granular circular shape. Figure 4.24 shows the wave amplitude and time histories of free surface elevation for 20 seconds.

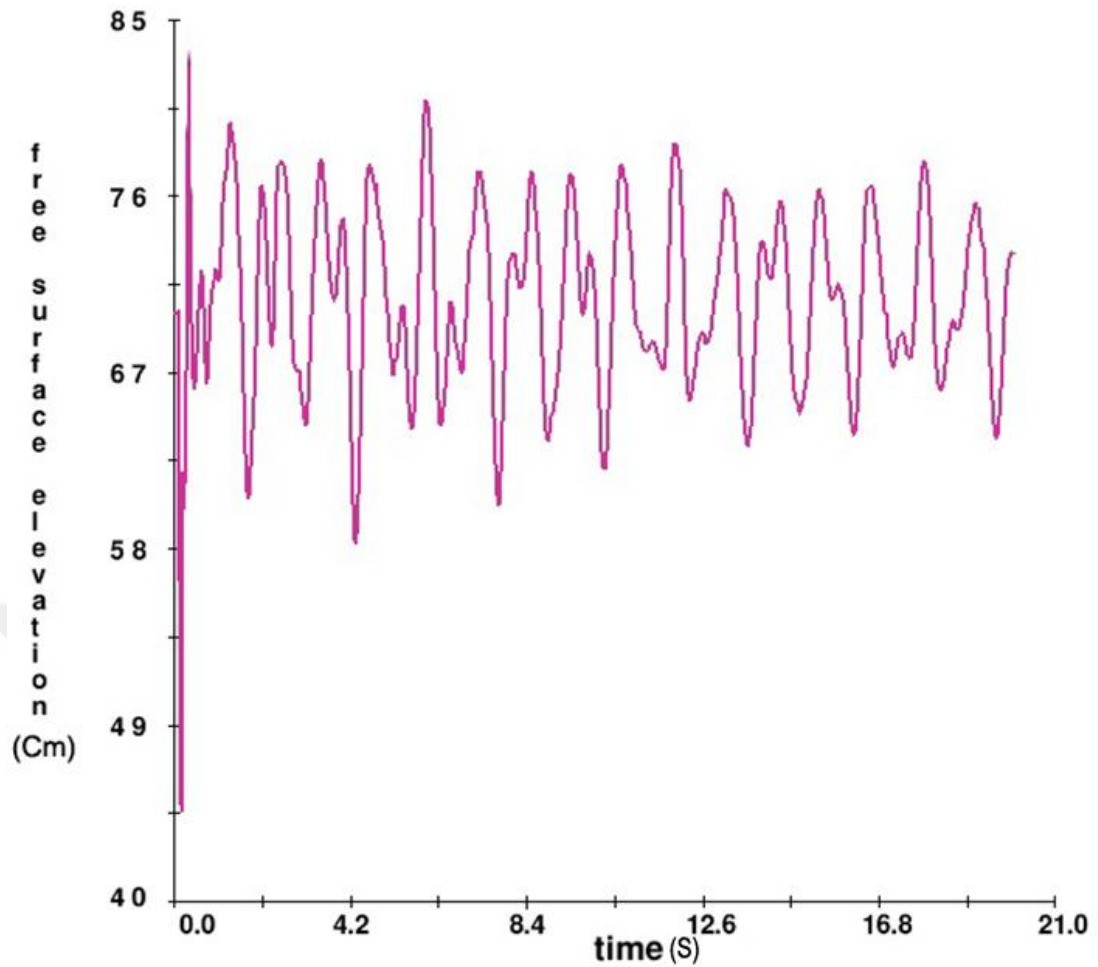


**Figure 4.24 :** Numerically-derived wave amplitudes for non-granular landslide at  $y=7\text{m}$  (cross section A-A) for 20 seconds

The calculated maximum and minimum wave heights at both situations show the difference between granular and non-granular circular shape geometries.

However, Figure 4.25 shows a slight phase difference together. Thus, the granular and non-granular shapes change the generated wave less than 9%.

Table 4.4 shows the variations of water surface elevation (wave) for subaerial granular circular landslide geometry and subaerial non-granular circular landslide geometry obtained from Flow-3D models for 20 seconds.

The maximum and minimum levels of water (wave heights) for subaerial non-granular circular landslide geometry are 84 and 45 cm respectively, so the water level changes 39 cm.

On the other hand the maximum and minimum levels of water (wave heights) for subaerial granular circular landslide geometry are 82 and 54 cm respectively, so the water level changes 28 cm.

**Table 4.4 :** Variations of water surface elevation (wave) for subaerial granular rectangular landslide geometry and subaerial non-granular circular landslide geometry obtained from Flow-3D models for 10 s.

| Time (s)                                           | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----------------------------------------------------|----|----|----|----|----|----|----|----|----|----|----|
| Water Surface Elevation(cm) non-granular landslide | 70 | 45 | 81 | 60 | 58 | 80 | 62 | 72 | 73 | 59 | 74 |
| Water Surface Elevation (cm) Granular landslide    | 70 | 55 | 81 | 74 | 65 | 72 | 70 | 63 | 74 | 69 | 73 |

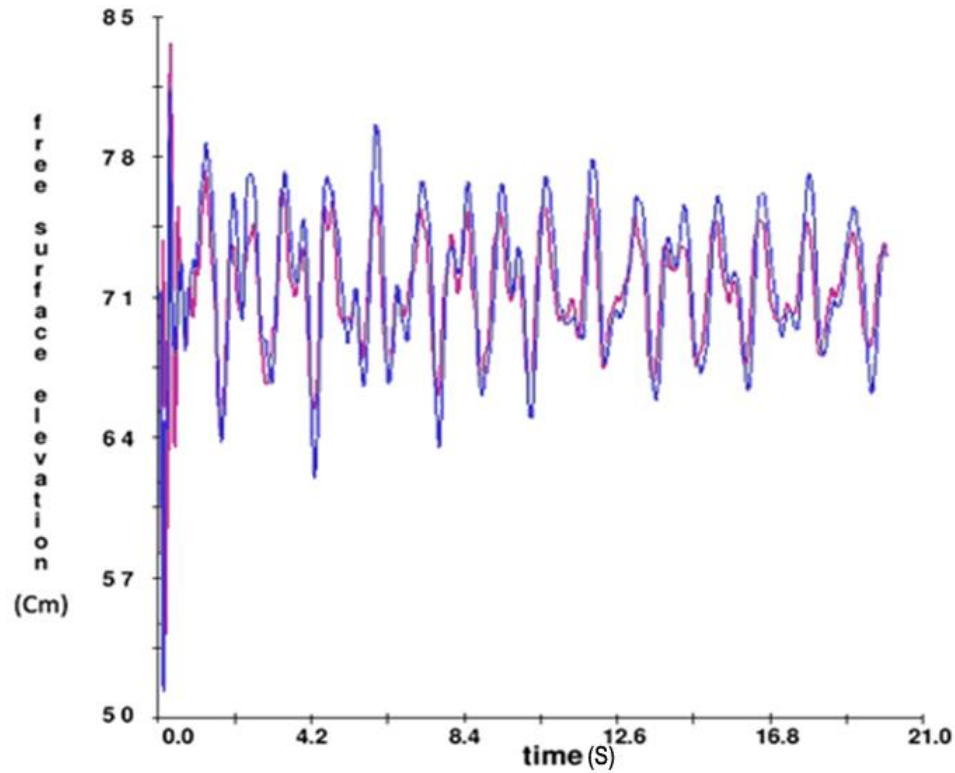


**Figure 4.25 :** Time histories of free surface elevation at  $y=7$  m obtained from Flow-3D models.

Red line : granular circular landslide geometry

Blue line : non-granular circular landslide geometry

#### 4.4 Result

The simulated results indicate the complex flow patterns in the lake in terms of velocity field, and free surface profiles. The numerical results of wave amplitudes and velocity magnitudes for circular, rectangular and triangular landslide geometries were applied to the sliding materials computed, which were used by geotechnical engineers to study the stabilization of the slope.

On the basis of the obtained results, the following conclusions can be drawn:

- Circular landslide behavior was compared with rectangular and triangular shapes during wave propagation; hence it was expected that the wave amplitude had the highest and lowest values in triangular, and circular shapes, respectively.
- It is depicted that the circular shape had the lowest value of wave amplitude, and triangular shape had the highest wave amplitude during this modeling

and triangular landslide had the most absolute values of horizontal and vertical forces during and after the initial wave generation.

The results of numerical analyses demonstrate that the general pattern of wave in all cases is the same but the amplitude and period are different. The numerical analyses show that the maximum wave crest amplitude in subaerial induced waves was strongly affected by deformation and by landslide shape.

Slide deformation made a maximum reduction on wave crest amplitude down to 35% and a maximum increase up to 30% on period, although no strong changes in general pattern of subaerial impulse wave features.

Slide shape did not strongly affect the general feature of impulse wave and at most the amplitude and period were changed less than 10%. Finally, the results of the Navier-Stokes model show that waves generated were highly dependent upon the details of slide mechanism and kinematics.

The model extended for simulating impulsive waves was caused by subaerial landslides entering a water body. A set of three-dimensional experimental data was used to validate the extended model. The time phase differences and the estimation error of the wave amplitudes were less than 15% and 5%, respectively.

The estimation error of the wave amplitude for the majority of the simulated experiments is less than 1%. Therefore, the extended model is able to simulate subaerial-landslide-generated waves with a degree of accuracy similar to that observed for the simulated submarine-landslide-generated waves in generation and propagation stages.

## 5. CASE STUDY MODELING ANALYSES AND RESULTS

### 5.1 Introduction

In this thesis, to study the wave generated by landslide, a real case in addition to channel modeling, is required. Subaerial Landslide Generated Waves (SLGW) generation and propagation are studied numerically for a real case. For this aim, the Maku Dam reservoir, in the north of Iran, is considered as the case study (Figure 5.1).

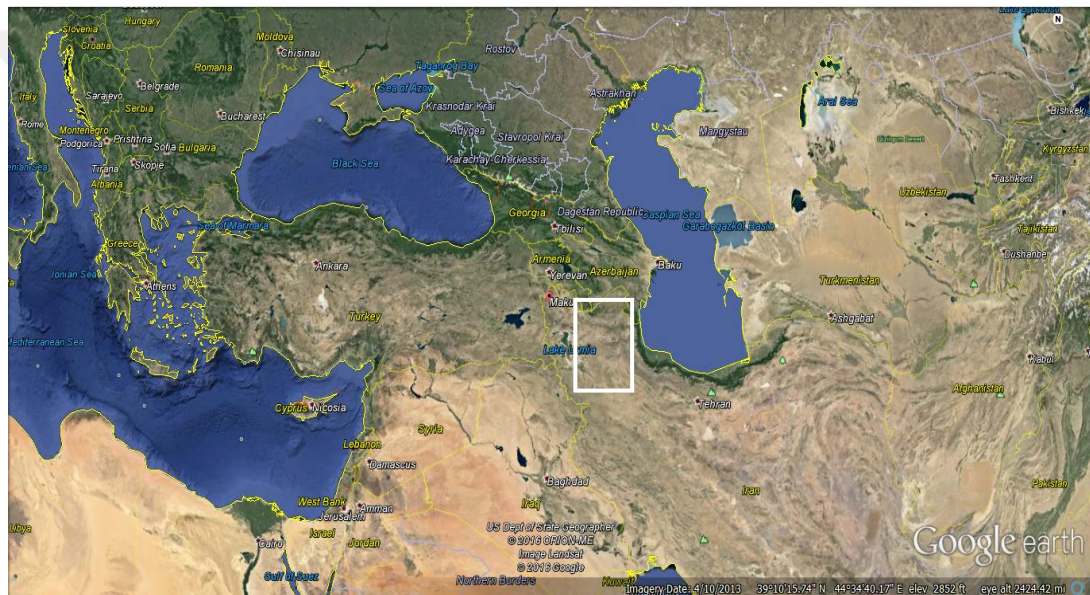


**Figure 5.1 :** The Google map view of Maku Dam

The Maku (Barun) Dam is located in the north part of Maku town, West Azarbaijan Province, Iran, in  $11^{\circ}39'17''$  north latitude and  $44^{\circ}28'55''$  east longitude, on the Zangmar River, which originates from the mountains above Maku, along the Turkish-Iranian border, not far from Mount Ararat and flows south and east into the Araxes at the town of Poldasht (Figure 5.2).



**Figure 5.2 :** Location of the Maku Dam, 11°39'17" N and 44°28'55" E. (Google earth map)

The Maku Dam is 75m high storage earth dam, with a reservoir capacity of 137 Mm<sup>3</sup> (Figure 5.3). Length and width of dam are 350m and 10m respectively. The dam crest level is 1699m from sea level (Figure 5.4b).



**Figure 5.3 :** Top view of the Maku Dam reservoir

The Maku Dam is located in a seismic region (Figure 5.4a) where the Badavli fault is located near the dam site; thus, seismic conditions intensify its crucial landslide-susceptibility status.



**Figure 5.4 :** (a) Satellite image of the Maku Dam site and the existing faults. (b) An oblique view of the Maku Dam

According to geological investigations, multiple factors such as rainfall, successive freezing–melting, pore water pressure changes, sequential changes in underground water level and weathering initiate the formation and extension of large number of tensile cracks along the Maku reservoir beaches (Figure 5.5b), which form some areas of instability.

One of the most dangerous areas of instability is located on the west beach with the horizontal distance of 235 m from the dam axis (Figure 5.5c, d).

Another significant area of instability is a circular shape instability located on the eastern beach with the horizontal distance of 230 m from the dam axis (Figure 5.5a).



(a)



(b)



(c)



(d)

**Figure 5.5 :** (a) A possible slide on the east bank of the Maku Dam reservoir, and (b) its zoom-view. (c) A possible slide on the west bank of the Maku Dam reservoir, and (d) its zoom-view

According to the topographic map of the Maku Dam site, the landslide on the east beach is subaerial.

The landslide can potentially generate a tsunami. In this thesis, the landslide and water wave surface are modeled with Flow 3D software (Figure 5.6).

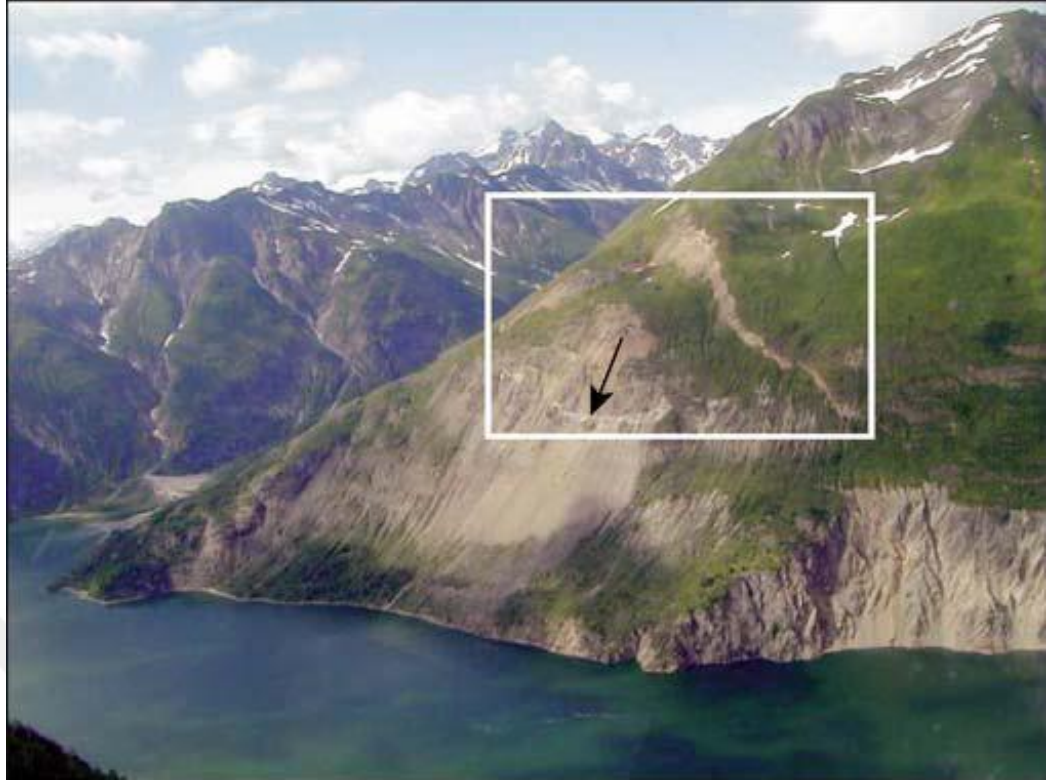


**Figure 5.6 :** Landslide perched above the shore of the Maku Dam with white box

## 5.2 Simulation Setup

Two scenarios are assumed to study and analyze the modeling of the Maku Dam:

1. Slide modeling with  $V=36.8 \text{ m}^3$
2. Slide modeling with  $V=58.2 \text{ m}^3$

The density of both slides in each model is equal to  $2 \text{ t/m}^3$ .

The velocity vectors and water run-up of these two modelings were also analyzed and compared in rainy and non-rainy seasons. Then the figure of the variations of water surface (wave) for two modelings in  $t=0 \sim t=120$  seconds was illustrated. Also the mean kinetic energy was calculated and depicted.

The numerical models were setup with Flow 3D software. The simulation in this study is performed in rigid subaerial landslide. The volume of rigid slide is  $36.8 \text{ m}^3$ . The density of the rigid slide is  $2 \text{ t/m}^3$ .

Table 5.1 shows some information about the total mesh size and the typical sizes of the grid elements.

The total number of real cells is 2,400,000. In this modeling the CPU time spent in each simulation is 64 hours. In this simulation setup viscous laminar flow model is used for simulations. Table 5.1. shows some information about mesh details.

**Table 5.1 :** Grid information for mesh blocks

| Mesh Information      | X direction | Y direction | Z direction |
|-----------------------|-------------|-------------|-------------|
| Number of real cells  | 180         | 140         | 95          |
| Minimum cell size (m) | 1           | 1           | 1           |
| Maximum cell size (m) | 3           | 2           | 2           |

Figure 5.7 shows the topographic view of the dam reservoir.

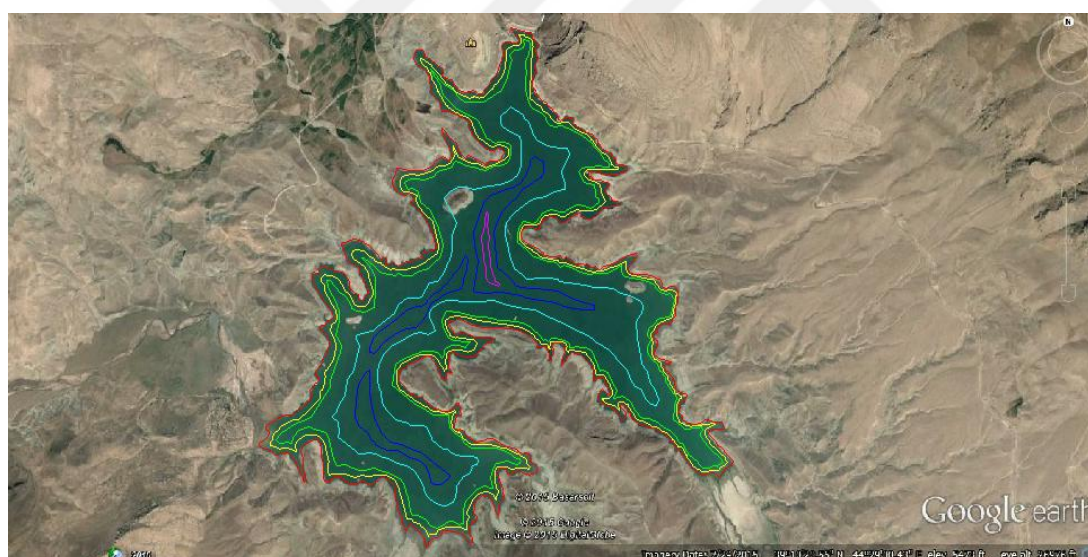


**Figure 5.7:** Topographic view of dam reservoir

Figure 5.8 shows 3D modeling of dam reservoir.



**Figure 5.8 :** 3D view of dam reservoir

Figure 5.9 shows 3D modeling of subaerial slide. This figure shows subaerial slide by red color and two cross section of A-A and B-B. The height of this right slide is about 2m, 2m width and 1m depth.

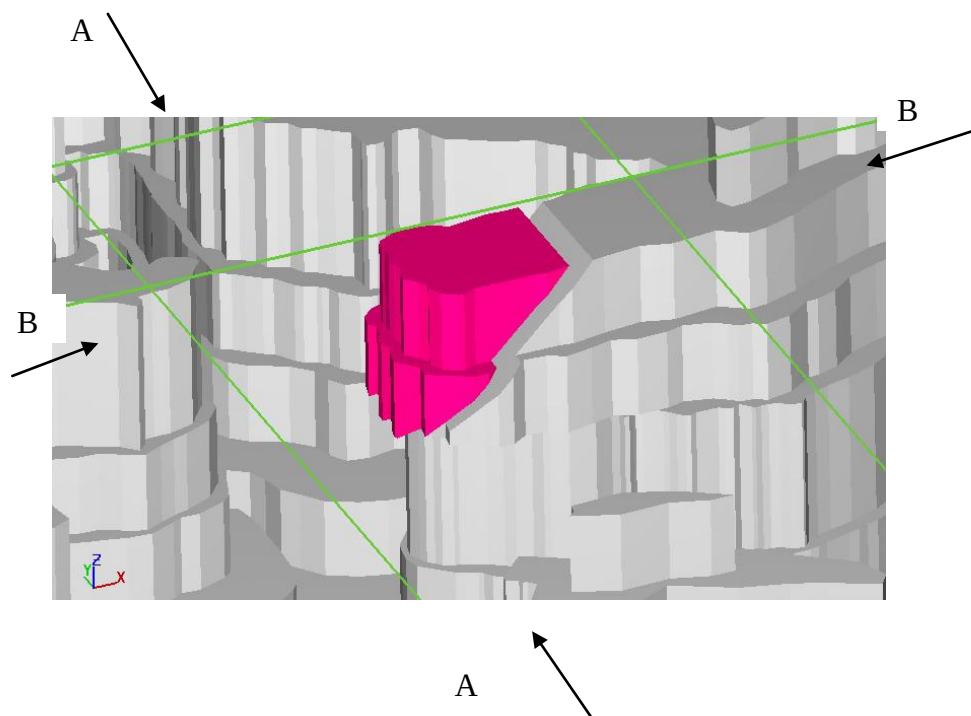


**Figure 5.9 :** 3D view of dam reservoir and subaerial slide ( $V=36.8 \text{ m}^3$ )

Figure 5.10 shows 3D modeling of dam reservoir, modeling and analysis with Flow3D software.

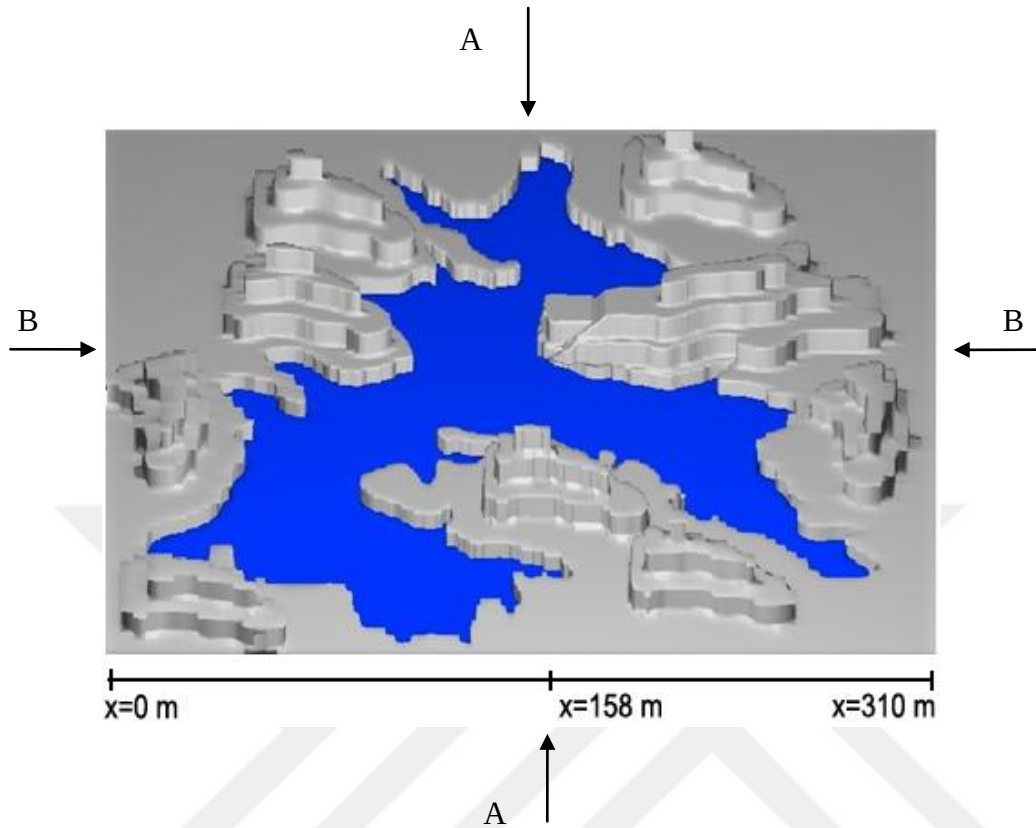
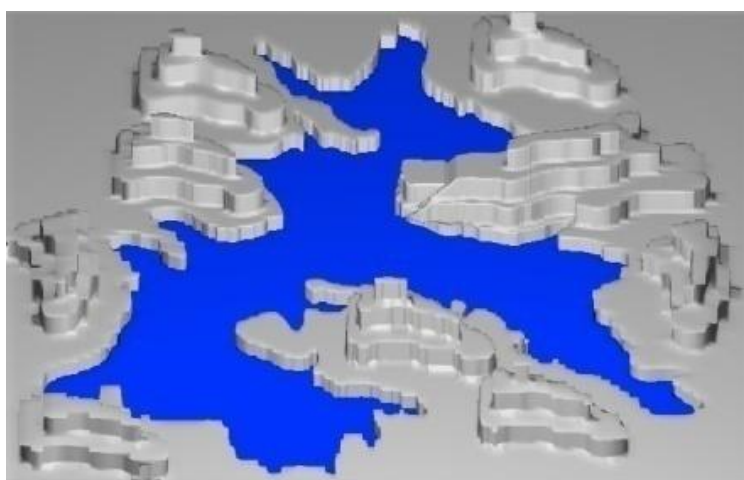


**Figure 5.10 :** 3D view of dam reservoir modeled with Flow-3D software

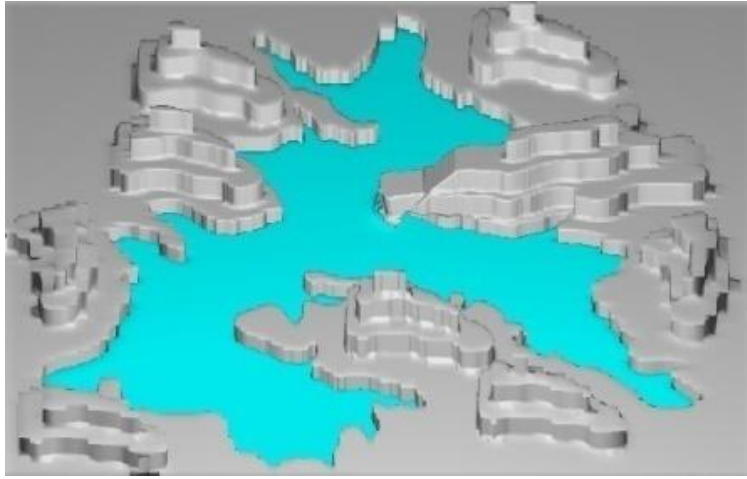
3D views of land sliding at  $t=0$ ,  $t=0.3$ ,  $t=0.5$ ,  $t=0.8$ ,  $t=1$ ,  $t=1.3$ ,  $t=1.5$ ,  $t=2$ ,  $t=50$  and  $t=120$  seconds for subaerial landslide is shown in Figure 5.11.



$t=0$  sec.

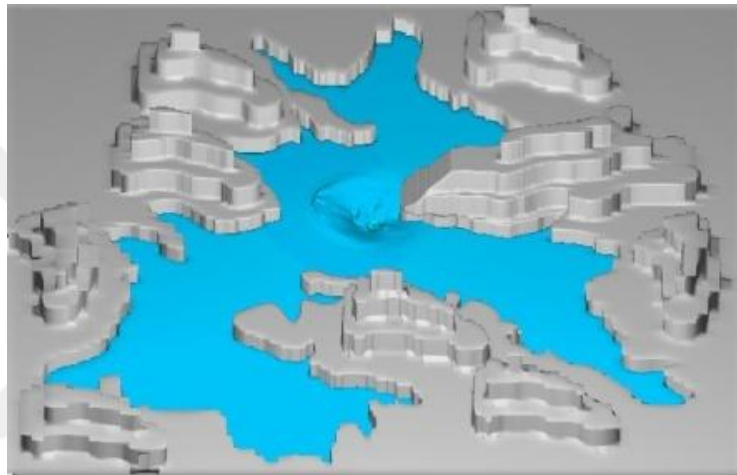
(a)

**Figure 5.11 :** 3D views of land sliding for subaerial landslide at different times: (a)  $t=0.0$  sec., (b)  $t=0.3$  sec., (c)  $t=0.5$  sec., (d)  $t=0.8$  sec., (e)  $t=1.0$  sec., (f)  $t=1.3$  sec., (g)  $t=1.5$  sec., (h)  $t=2.0$  sec., (i)  $t=50$  sec., (j)  $t=120$  sec.



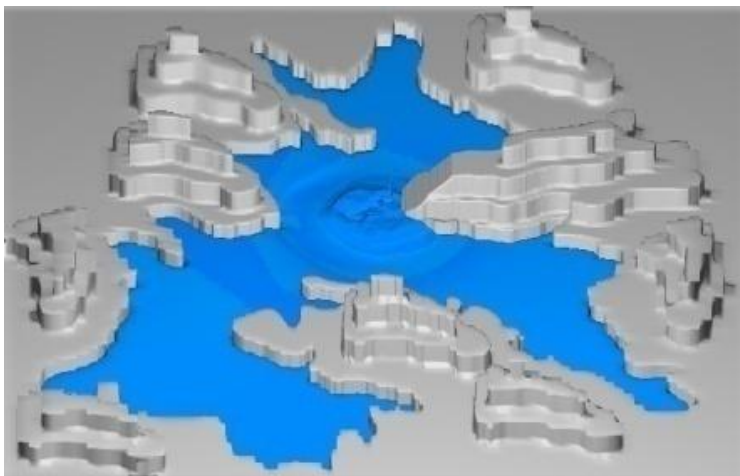
t=0.3 sec.

(b)



t=0.5 sec.

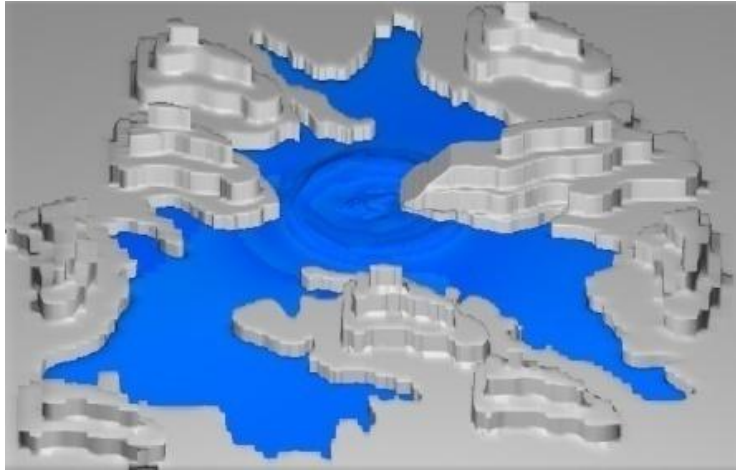
(c)



t=0.8 sec.

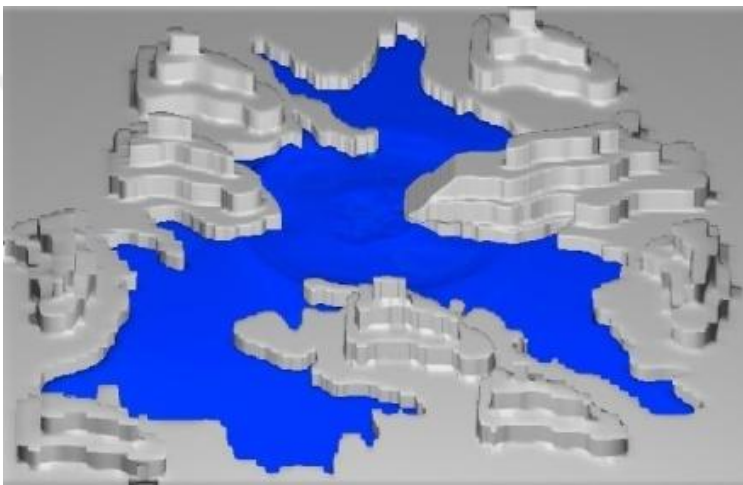
(d)

**Figure 5.11 (continued) :** 3D views of land sliding for subaerial landslide at different times: (a) t=0.0 sec., (b) t=0.3 sec., (c) t=0.5 sec., (d) t=0.8 sec., (e) t=1.0 sec., (f) t=1.3 sec., (g) t=1.5 sec., (h) t=2.0 sec., (i) t=50 sec., (j) t=120 sec.



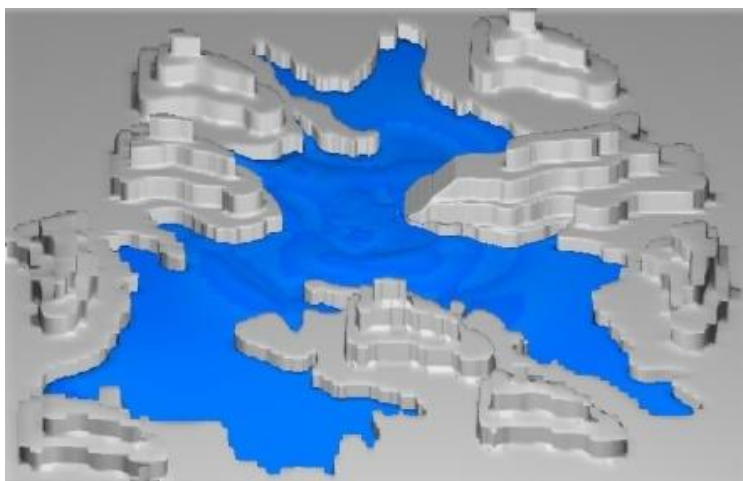
t=1.0 sec.

(e)



t=1.3 sec.

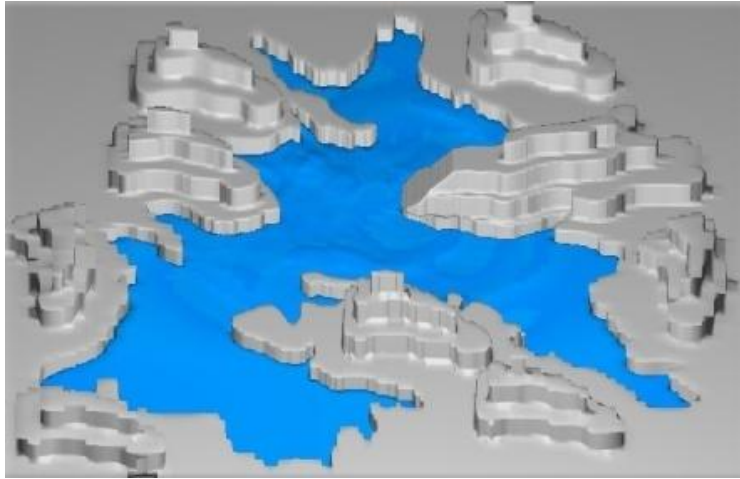
(f)



t=1.5 sec.

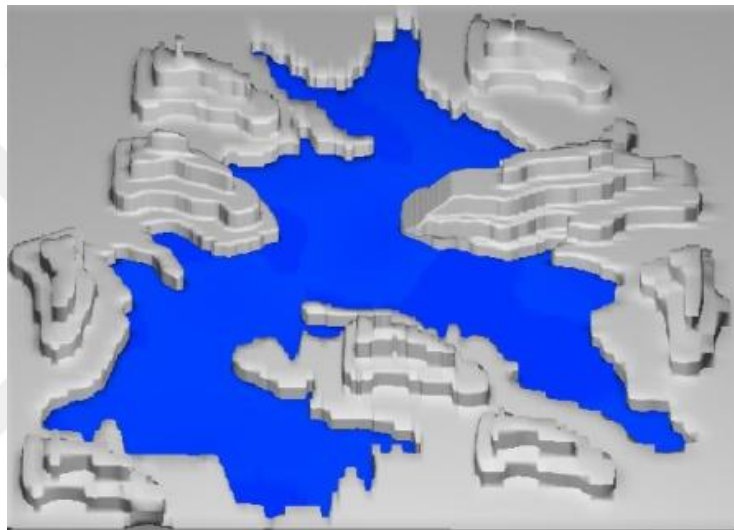
(g)

**Figure 5.11 (continued) :** 3D views of land sliding for subaerial landslide at different times: (a)  $t=0.0$  sec., (b)  $t=0.3$  sec., (c)  $t=0.5$  sec., (d)  $t=0.8$  sec., (e)  $t=1.0$  sec., (f)  $t=1.3$  sec., (g)  $t=1.5$  sec., (h)  $t=2.0$  sec., (i)  $t=50$  sec., (j)  $t=120$  sec.



t=2.0 sec.

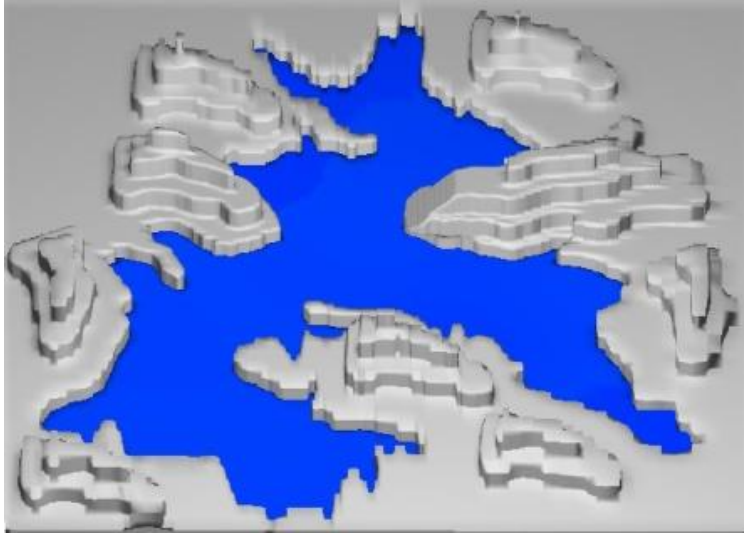
(h)



t=50 sec.

(i)

**Figure 5.11 (continued) :** 3D views of land sliding for subaerial landslide at different times: (a) t=0.0 sec., (b) t=1.0 sec., (c) t=2.0 sec., (d) t=3.0 sec., (e) t=4.0 sec., (f) t=5.0 sec., (g) t=6.0 sec., (h) t=7.0 sec., (i) t=8.0 sec., (j) t=9.0 sec.

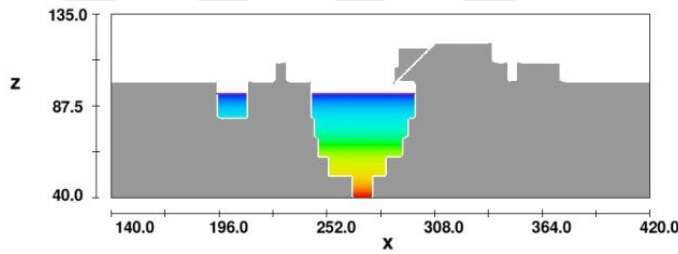


t=120 sec.

(j)

**Figure 5.11 (continued) :** 3D views of land sliding for subaerial landslide at different times: (a)  $t=0.0$  sec., (b)  $t=0.3$  sec., (c)  $t=0.5$  sec., (d)  $t=0.8$  sec., (e)  $t=1.0$  sec., (f)  $t=1.3$  sec., (g)  $t=1.5$  sec., (h)  $t=2.0$  sec., (i)  $t=50$  sec., (j)  $t=120$  sec.

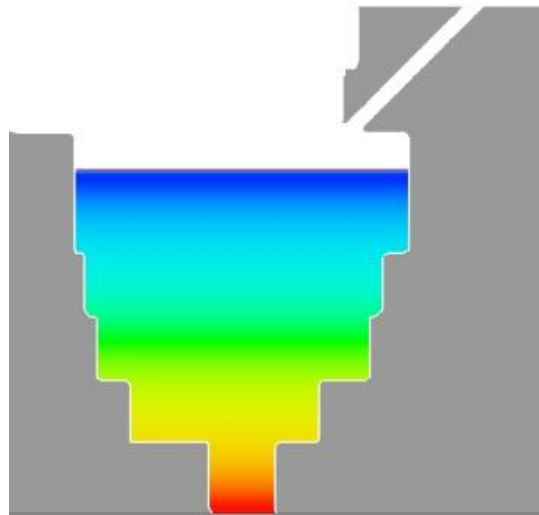
Figure 5.12 shows velocity vectors at  $t=0$ ,  $t=0.2$ ,  $t=0.3$ ,  $t=0.5$ ,  $t=0.7$ ,  $t=1.5$ ,  $t=10$ ,  $t=50$ ,  $t=100$  and  $t=120$  seconds for subaerial landslide.



t=0 sec.

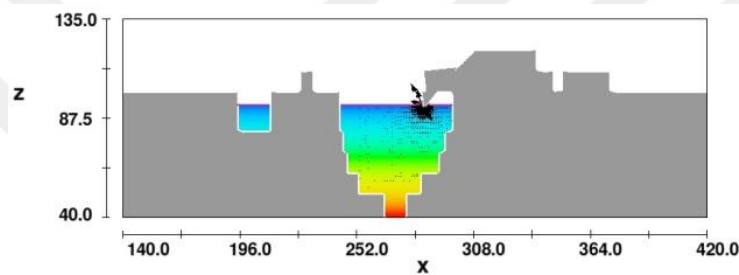
(a)

**Figure 5.12 :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a)  $t=0$  sec., (b)  $t=0$  sec. in more details, (c)  $t=0.2$  sec., (d)  $t=0.2$  sec. in more details, (e)  $t=0.3$  sec., (f)  $t=0.3$  sec. in more details, (g)  $t=0.5$  sec., (h)  $t=0.5$  sec. in more details, (i)  $t=0.7$  sec., (j)  $t=0.7$  sec. in more details, (k)  $t=1.0$  sec., (l)  $t=1.0$  sec. in more details, (m)  $t=10$  sec., (n)  $t=10$  sec. in more details, (o)  $t=50$  sec., (p)  $t=50$  sec. in more details, (q)  $t=100$  sec., (r)  $t=100$  sec. in more details, (s)  $t=120$  sec., (t)  $t=120$  sec. in more details



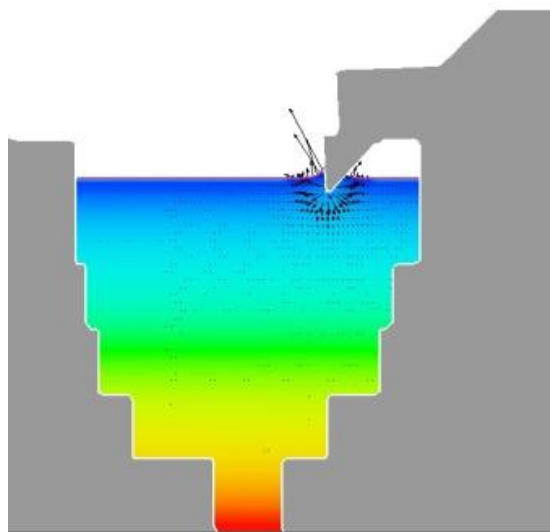
t=0 sec.

(b)



t=0.2 sec.

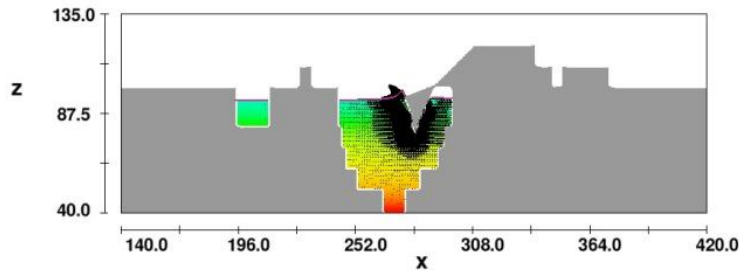
(c)



t=0.2 sec.

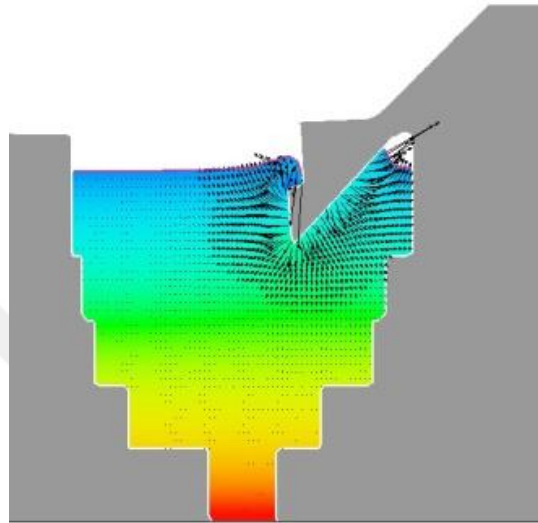
(d)

**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a) t=0 sec., (b) t=0 sec. in more details, (c) t=0.2 sec., (d) t=0.2 sec. in more details, (e) t=0.3 sec., (f) t=0.3 sec. in more details, (g) t=0.5 sec., (h) t=0.5 sec. in more details, (i) t=0.7 sec., (j) t=0.7 sec. in more details, (k) t=1.0 sec., (l) t=1.0 sec. in more details, (m) t=10 sec., (n) t=10 sec. in more details, (o) t=50 sec., (p) t=50 sec. in more details, (q) t=100 sec., (r) t=100 sec. in more details, (s) t=120 sec., (t) t=120 sec. in more details



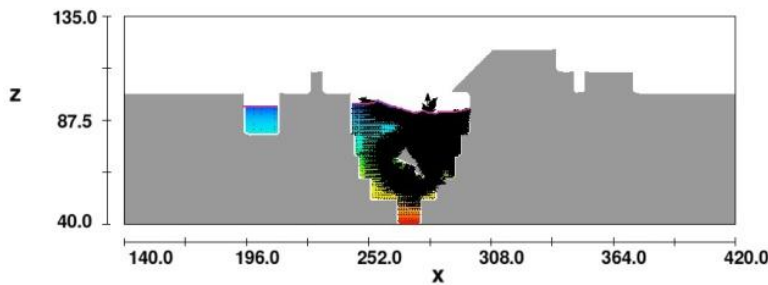
t=0.3 sec.

(e)



t=0.3 sec.

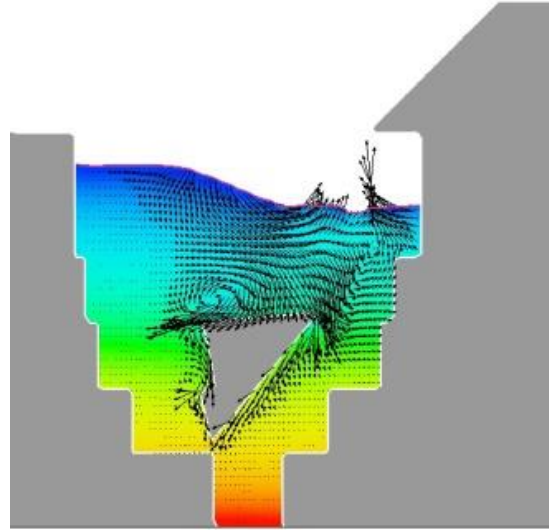
(f)



t=0.5 sec.

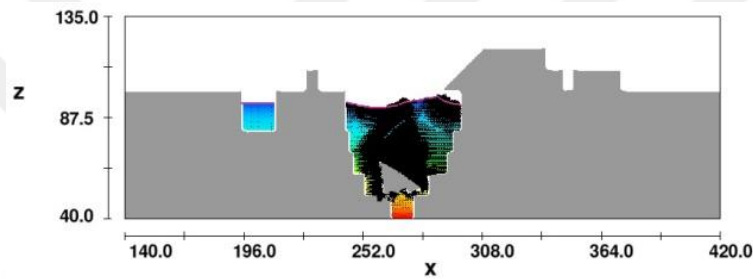
(g)

**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a) t=0 sec., (b) t=0 sec. in more details, (c) t=0.2 sec., (d) t=0.2 sec. in more details, (e) t=0.3 sec., (f) t=0.3 sec. in more details, (g) t=0.5 sec., (h) t=0.5 sec. in more details, (i) t=0.7 sec., (j) t=0.7 sec. in more details, (k) t=1.0 sec., (l) t=1.0 sec. in more details, (m) t=10 sec., (n) t=10 sec. in more details, (o) t=50 sec., (p) t=50 sec. in more details, (q) t=100 sec., (r) t=100 sec. in more details, (s) t=120 sec., (t) t=120 sec. in more details



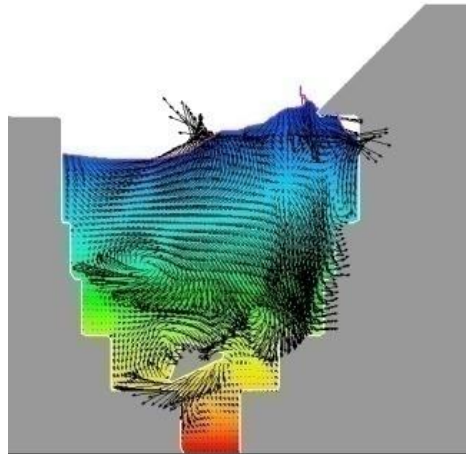
t=0.5 sec.

(h)



t=0.7 sec.

(i)



t=0.7 sec.

(j)

**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a) t=0 sec., (b) t=0 sec. in more details, (c) t=0.2 sec., (d) t=0.2 sec. in more details, (e) t=0.3 sec., (f) t=0.3 sec. in more details, (g) t=0.5 sec., (h) t=0.5 sec. in more details, (i) t=0.7 sec., (j) t=0.7 sec. in more details, (k) t=1.0 sec., (l) t=1.0 sec. in more details, (m) t=10 sec., (n) t=10 sec. in more details, (o) t=50 sec., (p) t=50 sec. in more details, (q) t=100 sec., (r) t=100 sec. in more details, (s) t=120 sec., (t) t=120 sec. in more details

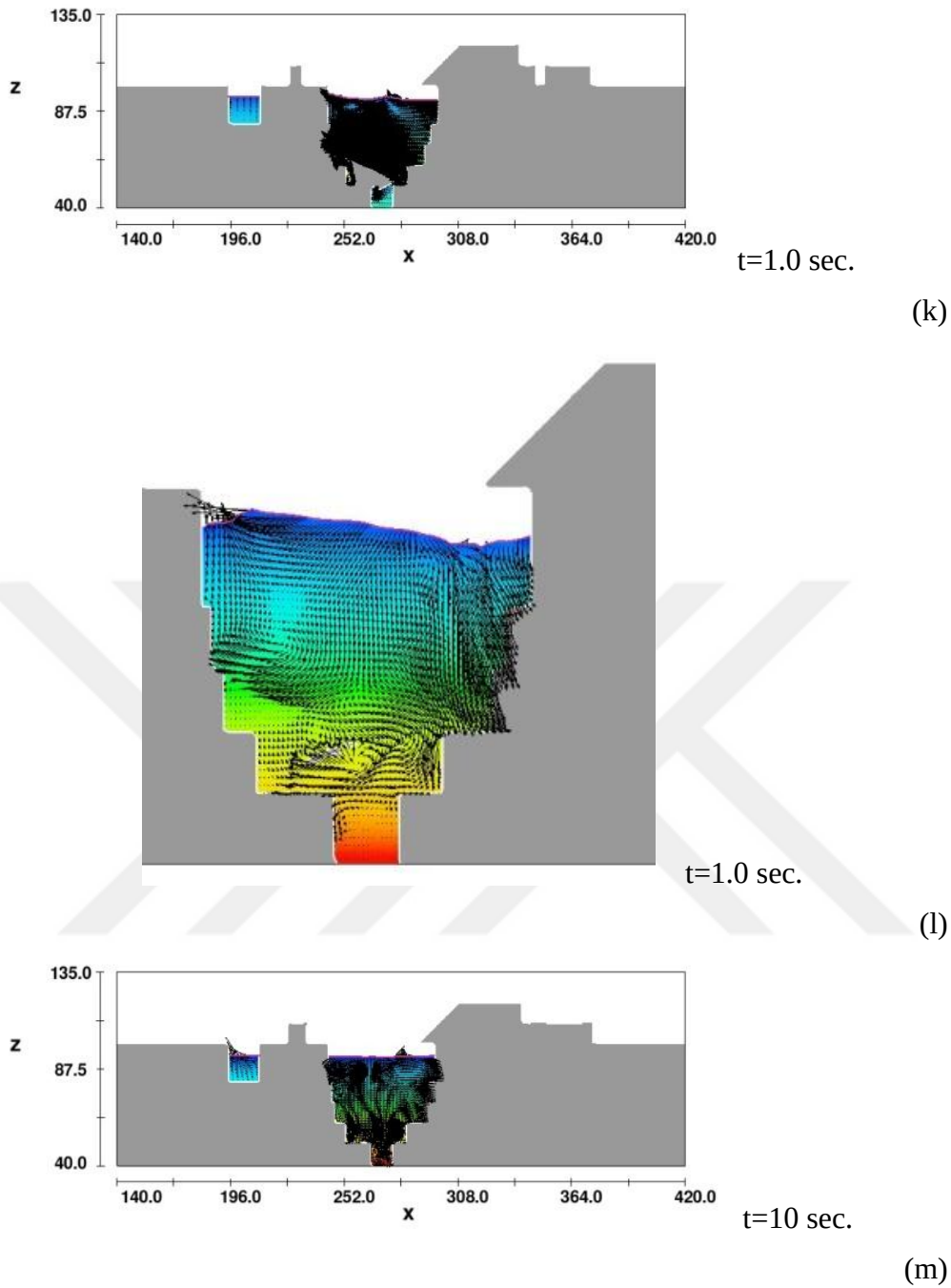
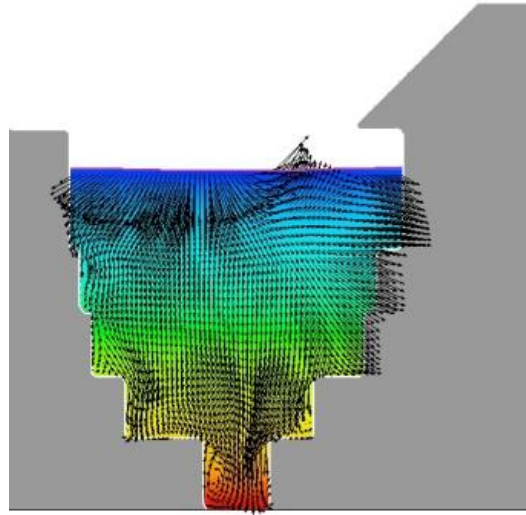
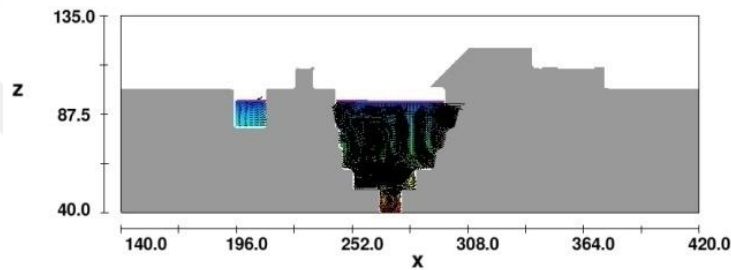


**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B) : (a)  $t=0$  sec., (b)  $t=0$  sec. in more details, (c)  $t=0.2$  sec., (d)  $t=0.2$  sec. in more details, (e)  $t=0.3$  sec., (f)  $t=0.3$  sec. in more details, (g)  $t=0.5$  sec., (h)  $t=0.5$  sec. in more details, (i)  $t=0.7$  sec., (j)  $t=0.7$  sec. in more details, (k)  $t=1.0$  sec., (l)  $t=1.0$  sec. in more details, (m)  $t=10$  sec., (n)  $t=10$  sec. in more details, (o)  $t=50$  sec., (p)  $t=50$  sec. in more details, (q)  $t=100$  sec., (r)  $t=100$  sec. in more details, (s)  $t=120$  sec., (t)  $t=120$  sec. in more details



t=10 sec.

(n)



t=50 sec.

(o)

**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a) t=0 sec., (b) t=0 sec. in more details, (c) t=0.2 sec., (d) t=0.2 sec. in more details, (e) t=0.3 sec., (f) t=0.3 sec. in more details, (g) t=0.5 sec., (h) t=0.5 sec. in more details, (i) t=0.7 sec., (j) t=0.7 sec. in more details, (k) t=1.0 sec., (l) t=1.0 sec. in more details, (m) t=10 sec., (n) t=10 sec. in more details, (o) t=50 sec., (p) t=50 sec. in more details, (q) t=100 sec., (r) t=100 sec. in more details, (s) t=120 sec., (t) t=120 sec. in more details

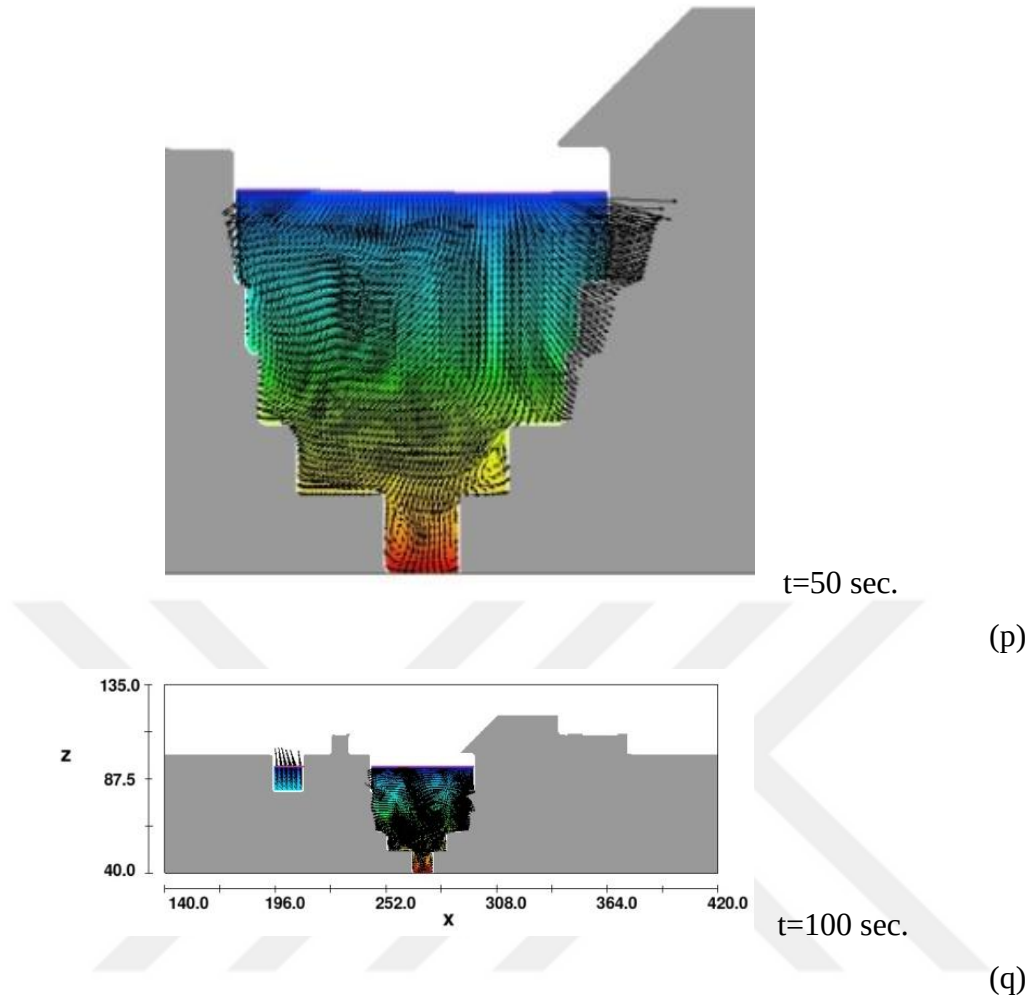
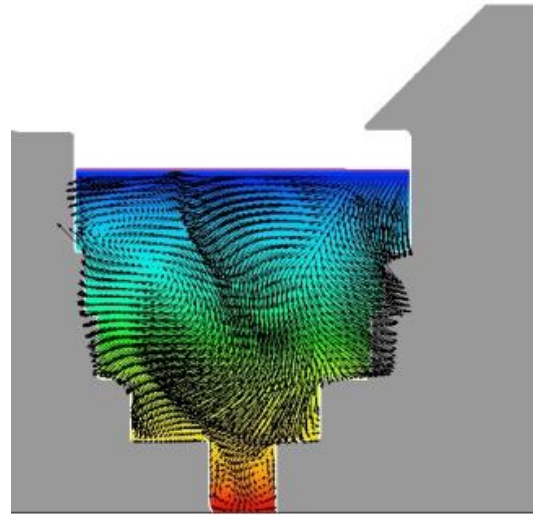
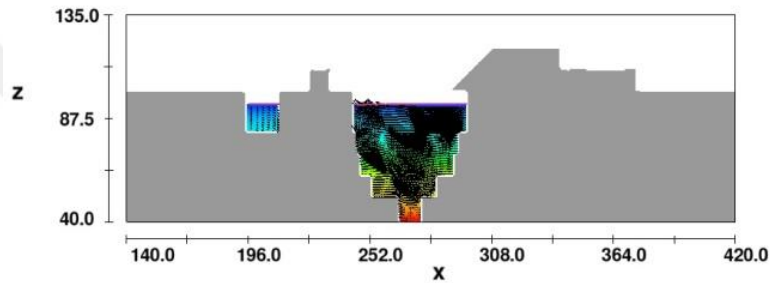


**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a)  $t=0$  sec., (b)  $t=0$  sec. in more details, (c)  $t=0.2$  sec., (d)  $t=0.2$  sec. in more details, (e)  $t=0.3$  sec., (f)  $t=0.3$  sec. in more details, (g)  $t=0.5$  sec., (h)  $t=0.5$  sec. in more details, (i)  $t=0.7$  sec., (j)  $t=0.7$  sec. in more details, (k)  $t=1.0$  sec., (l)  $t=1.0$  sec. in more details, (m)  $t=10$  sec., (n)  $t=10$  sec. in more details, (o)  $t=50$  sec., (p)  $t=50$  sec. in more details, (q)  $t=100$  sec., (r)  $t=100$  sec. in more details, (s)  $t=120$  sec., (t)  $t=120$  sec. in more details



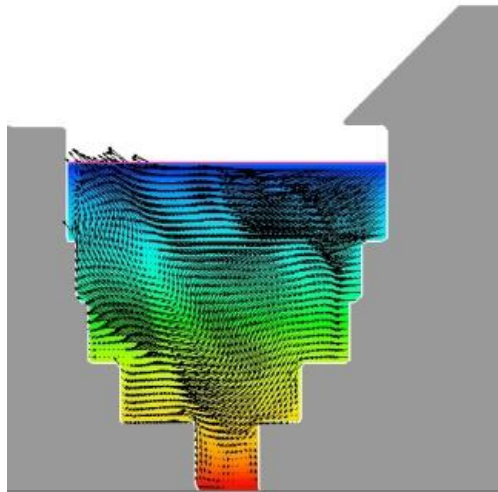
t=100 sec.

(r)



t=120 sec.

(s)



t=120 sec.

(t)

**Figure 5.12 (continued) :** Velocity vectors for subaerial landslide at different times (cross section B-B): (a) t=0 sec., (b) t=0 sec. in more details, (c) t=0.2 sec., (d) t=0.2 sec. in more details, (e) t=0.3 sec., (f) t=0.3 sec. in more details, (g) t=0.5 sec., (h) t=0.5 sec. in more details, (i) t=0.7 sec., (j) t=0.7 sec. in more details, (k) t=1.0 sec., (l) t=1.0 sec. in more details, (m) t=10 sec., (n) t=10 sec. in more details, (o) t=50 sec., (p) t=50 sec. in more details, (q) t=100 sec., (r) t=100 sec. in more details, (s) t=120 sec., (t) t=120 sec. in more details

The numerical results of wave amplitudes over time in locations at  $x=158\text{m}$  for subaerial landslide are presented in Figure 5.13. It shows the wave amplitude and time histories of free surface elevation.

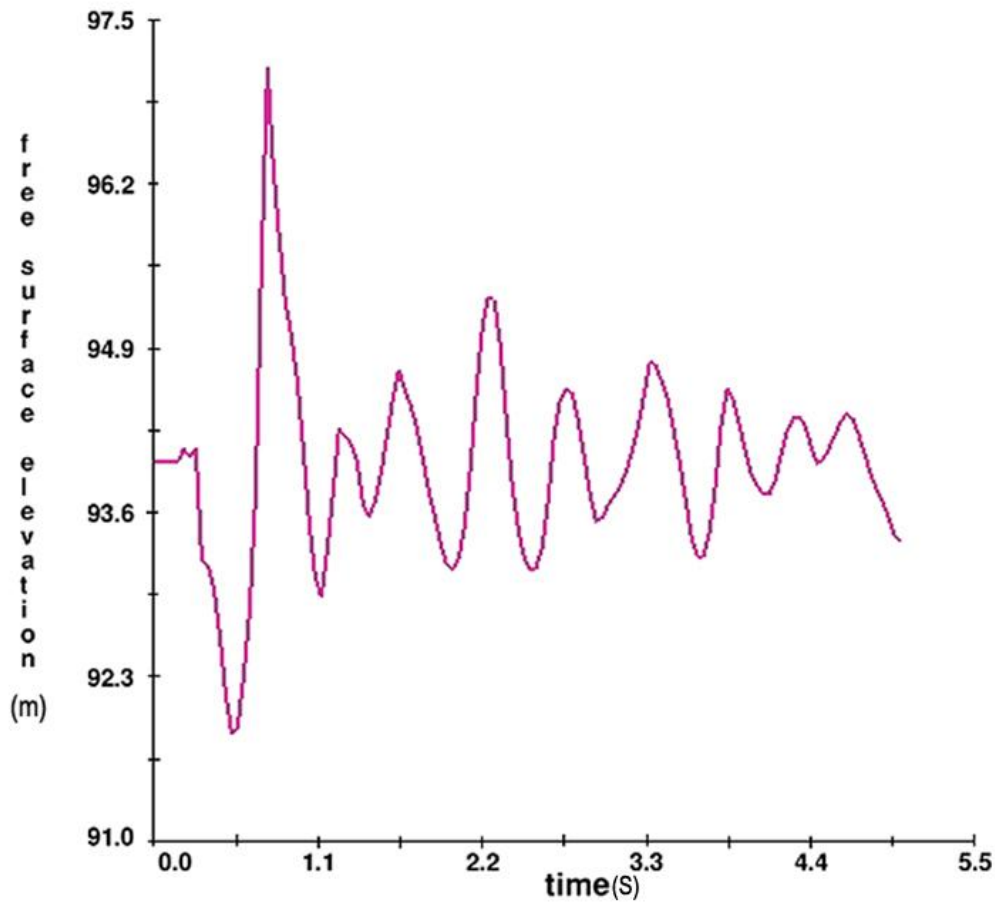


**Figure 5.13 :** Time histories of free surface elevation at  $x=158\text{ m}$  (cross section A-A) obtained from Flow-3D models

The numerical results of wave amplitudes over time in locations at  $x=158\text{m}$  for subaerial landslide are presented in Figure 5.14. It shows the wave amplitude and time histories of free surface elevation for 50 seconds.

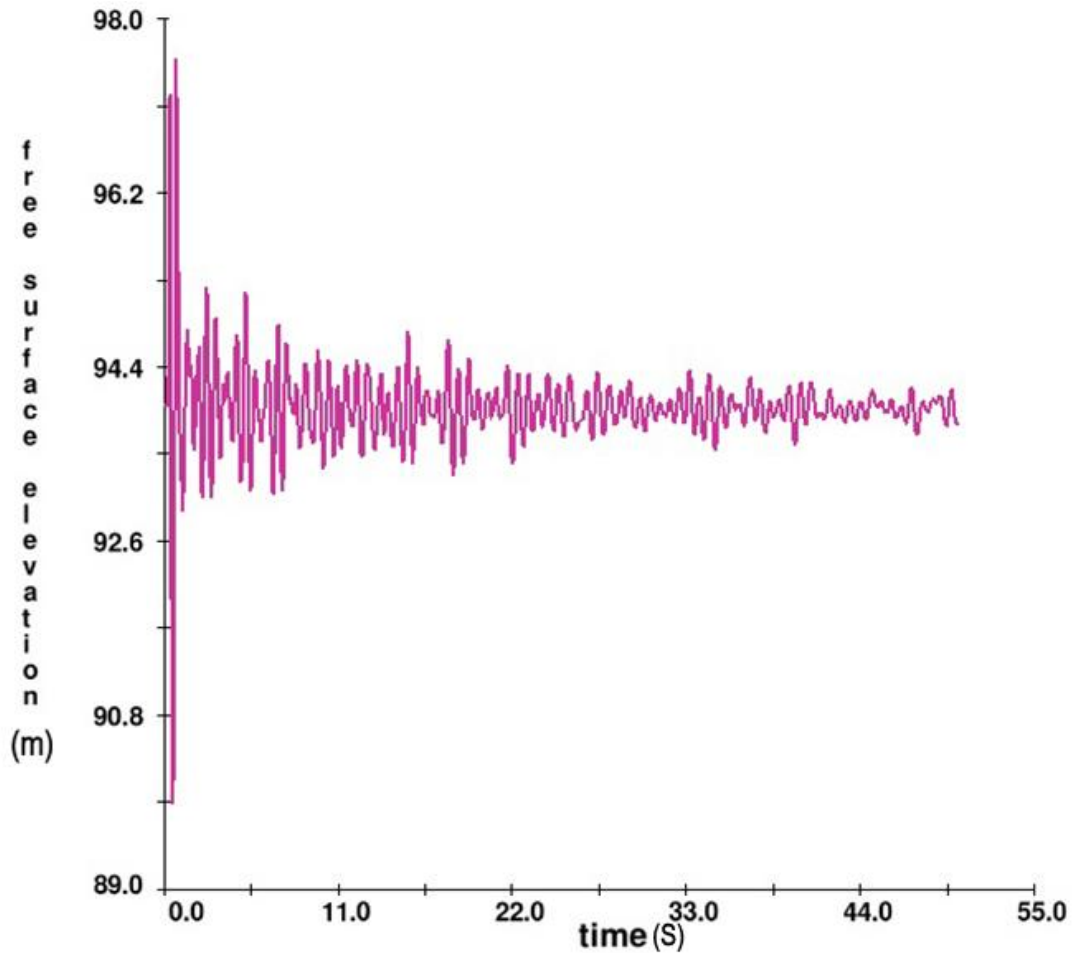


**Figure 5.14 :** Time histories of free surface elevation at  $x=158$  m (cross section A-A) obtained from Flow-3D models for 50s.

The numerical results of wave amplitudes over time in locations of  $X=158$ m for subaerial landslide are presented in Figure 5.15. It shows the wave amplitude and time histories of free surface elevation for 120 seconds.

In Figure 5.15, the modeling was implemented for 120 seconds. It was viewed that after the release of the slide into the reservoir, the height of water surface undergoes a sudden and violent fluctuation but the water fluctuation gradually decreases towards zero or the normal water level.

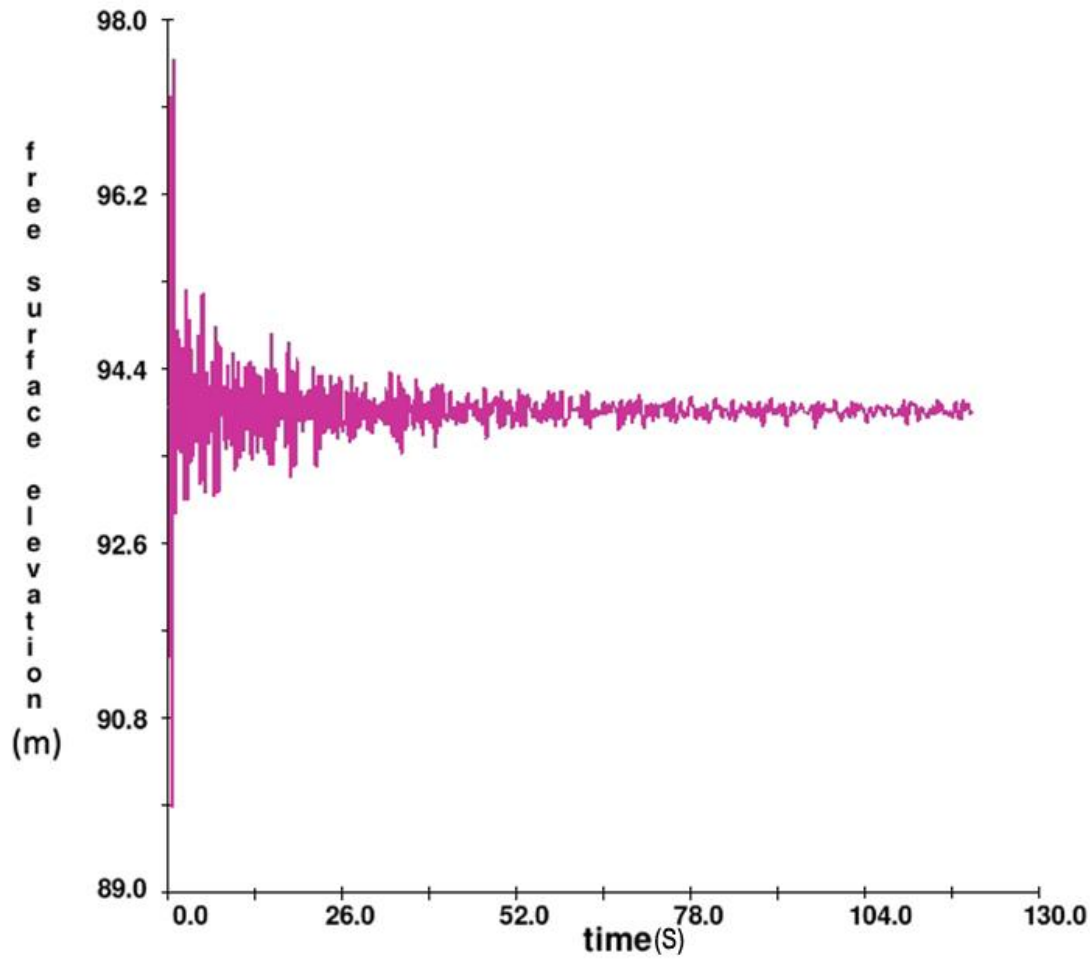


**Figure 5.15 :** Time histories of free surface elevation at  $x=158$  m (cross section A-A) obtained from Flow-3D models for 120s.

In the literature of landslide generated impulse waves, two different slide energies were introduced in comparison with the generated wave energy: the potential slide energy before slide release, and the kinetic slide energy upon impact.

The potential slide energy was applied to laboratory generated impulse waves by Johnson and Bermel and Wiegel.

The conversion from potential to kinetic energy upon impact may vary significantly between both laboratory studies and observed events due to the different friction losses.

The potential slide energy before release does not determine the kinetic slide impact energy. Therefore the kinetic slide impact energy is used in the following analysis of the slide to study wave energy conversion.

The numerical results of wave energy over time for subaerial landslide are presented in Figure 5.16. It shows the wave energy and time histories for 120 seconds.

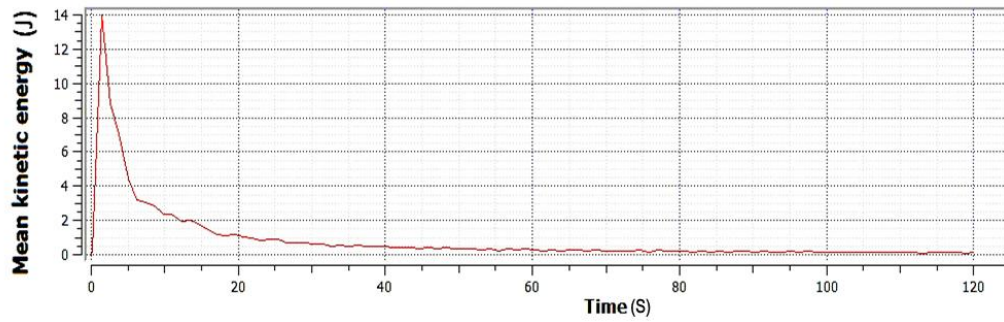


**Figure 5.16 :** Time histories of wave energy obtained from Flow-3D models for 120s.

### 5.3 Velocity Vectors

Table 5.2 shows the variations of velocity vectors and water surface elevation (wave) obtained from Flow-3D models for 100 seconds.

**Table 5.2 :** Variations of velocity vectors and water surface elevation (wave) obtained from Flow-3D models for 100 s.

| Time (s)                    | 0  | 10   | 20   | 30  | 40   | 50   | 60   | 70   | 80   | 90   | 100  |
|-----------------------------|----|------|------|-----|------|------|------|------|------|------|------|
| U (m/s)                     | 0  | -2.3 | 3.2  | 0.5 | 0.3  | 1.1  | -4.2 | 3    | 0    | -0.6 | 0.7  |
| V (m/s)                     | 0  | -1.8 | -2   | 1.6 | 1.4  | 0    | 0.5  | 2    | 1.8  | 0    | -0.4 |
| W (m/s)                     | 0  | -8   | 1.5  | 1.1 | -0.2 | 4.3  | -0.9 | 3.7  | -0.7 | -0.6 | -1.6 |
| Water Surface Elevation (m) | 94 | 93.7 | 94.1 | 93  | 94.4 | 93.8 | 93.9 | 93.6 | 94.1 | 94.4 | 93.5 |

Figure 5.17 shows the variations of velocity vectors (u, v, w) obtained from Flow-3D models for 120 seconds.

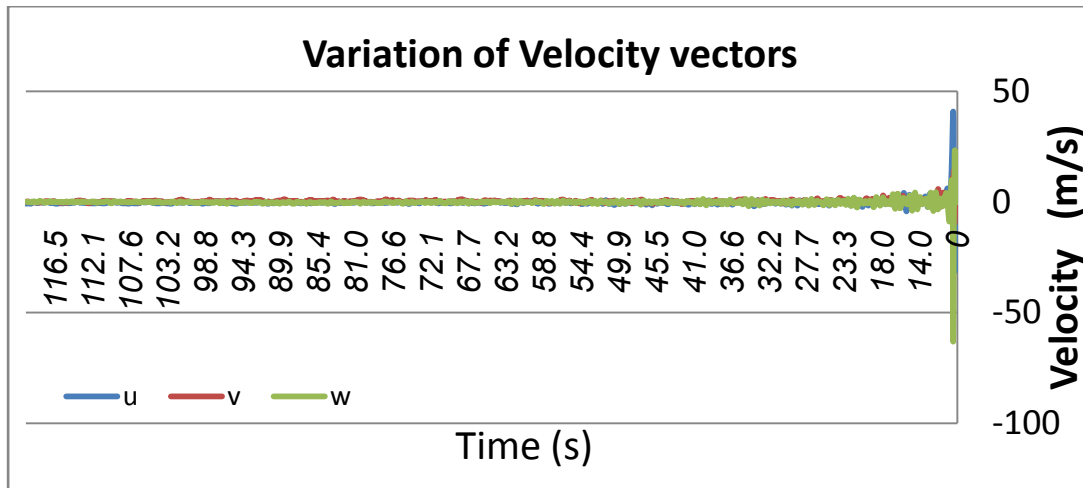


**Figure 5.17 :** Variations of velocity vectors (u, v, w) obtained from Flow 3D models for 120 seconds.

Table 5.3 shows variations of velocity vectors and water surface elevation (wave) obtained from Flow-3D models for 1.0 second. This table shows that the maximum level of water surface occurred at  $t=0.8$  second and the minimum level of water surface occurred at  $t=0.5$  second.

**Table 5.3 :** Variations of velocity vectors and water surface elevation (wave) obtained from Flow 3D models for 1.0 seconds.

| Time (s)                    | 0  | 0.1 | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  | 0.9  | 1.0  |
|-----------------------------|----|-----|------|------|------|------|------|------|------|------|------|
| U (m/s)                     | 0  | 0   | -0.5 | -21  | 38.1 | 38.0 | 19.6 | 10.5 | 6.7  | -2.9 | -2.3 |
| V (m/s)                     | 0  | 0   | -0.1 | -5.0 | 6.6  | 9.0  | 5.8  | 3.6  | 2.5  | -0.2 | -1.8 |
| W (m/s)                     | 0  | 0   | 0    | 2.7  | -52  | -11  | 9.8  | 8.6  | 5.8  | -5.9 | -8   |
| Water Surface Elevation (m) | 94 | 94  | 94   | 94.9 | 93.4 | 89.8 | 92.1 | 95.3 | 97.6 | 95.6 | 93.7 |

Figure 5.18 shows the variation of velocity vectors (u, v, w) obtained from Flow 3D models for 1.0 second.

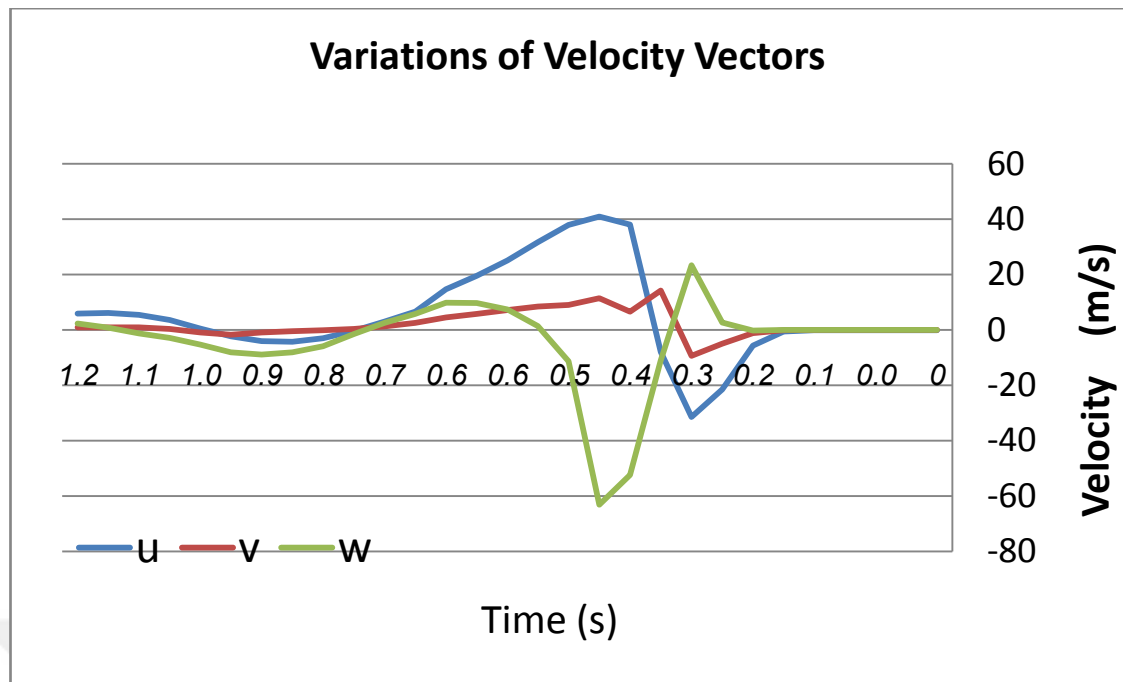


**Figure 5.18 :** Variations of velocity vectors (u, v, w) obtained from Flow-3D models for 1.0 second

### 5.5 Second Simulation Setup

The second numerical models were set-up with Flow 3D software. The simulation in this study is carried out in rigid subaerial landslide. The volume of rigid slide is  $58.2\text{m}^3$ . The density of the rigid slide is  $2\text{t/m}^3$ . Table 5.4 shows some information about the total mesh size and the typical sizes of the grid elements. Also the total number of real cells is 2,400,000. In this modeling the CPU time spent in simulation is 24 hours. In this study viscous laminar flow model are used for simulations. Table 5.4. shows some information about mesh details.

**Table 5.4 :** Grid information for mesh blocks

| Mesh Information      | X direction | Y direction | Z direction |
|-----------------------|-------------|-------------|-------------|
| Number of real cells  | 180         | 140         | 95          |
| Minimum cell size (m) | 1           | 1           | 1           |
| Maximum cell size (m) | 3           | 2           | 2           |

Figure 5.19 shows 3D modeling of dam reservoir, and the part that is likely to slip is shown with red marks.

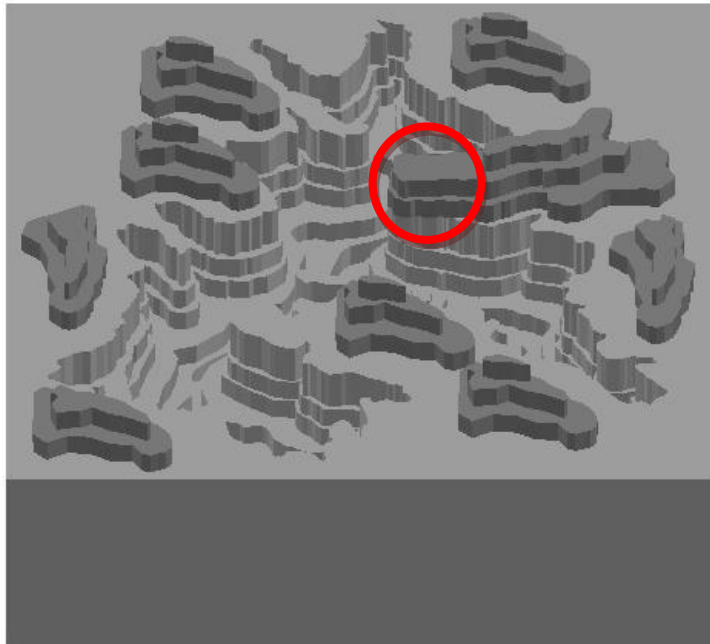


**Figure 5.19 :** 3D view of dam reservoir

Figure 5.20 shows 3D modeling of larger subaerial slide. This figure shows subaerial slide by red color and two cross sections A-A and B-B.

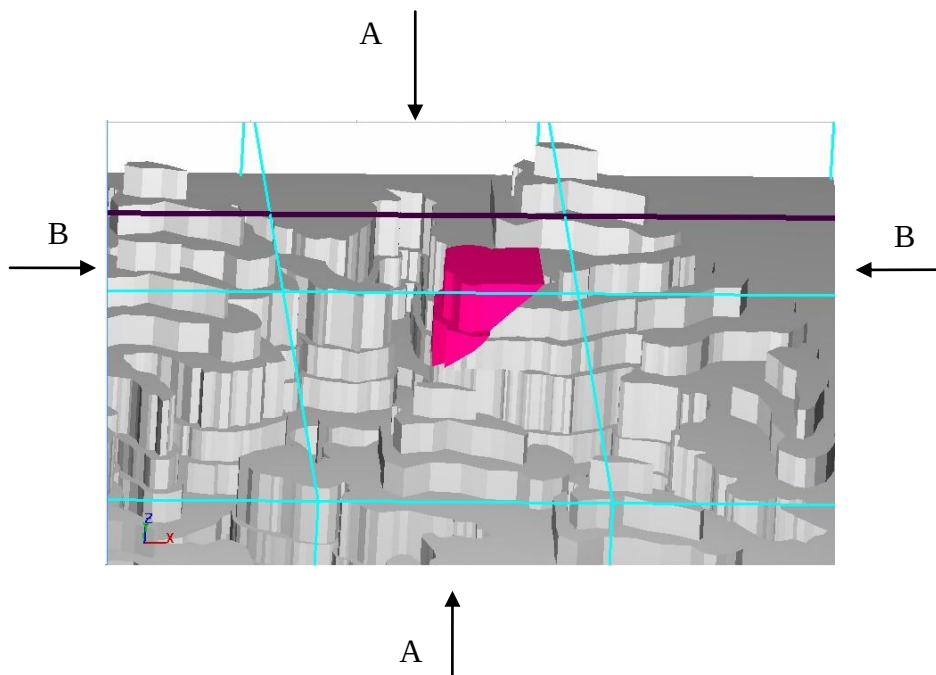


**Figure 5.20 :** 3D view of dam reservoir and subaerial slide

Figure 5.21 shows 3D modeling of dam reservoir, modeled and analyzed with Flow 3D software.

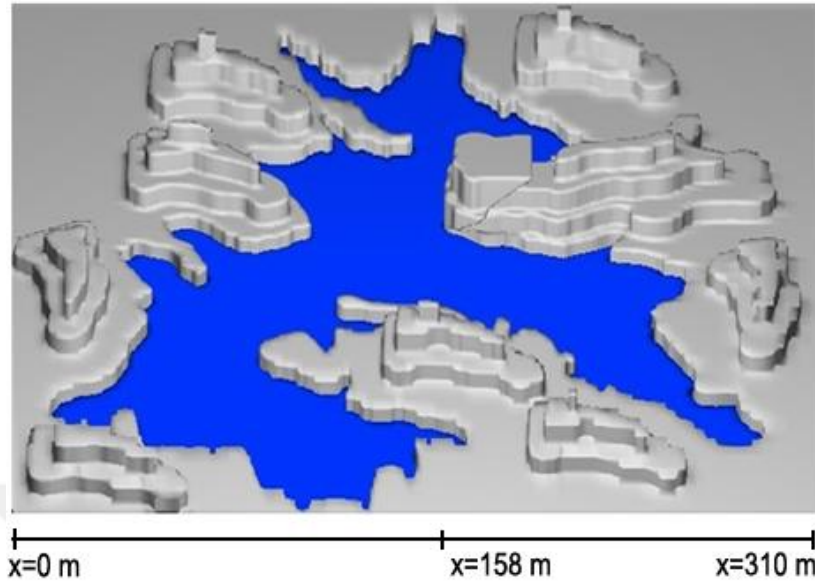
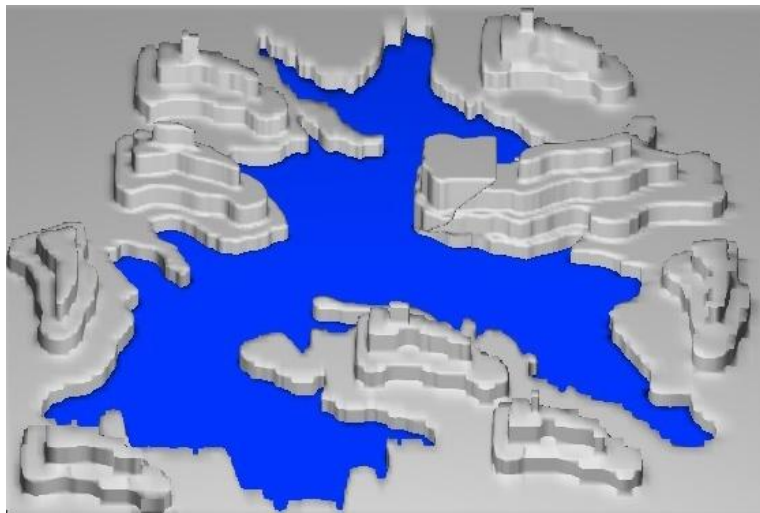


**Figure 5.21 :** 3D view of dam reservoir modeled with Flow3D software

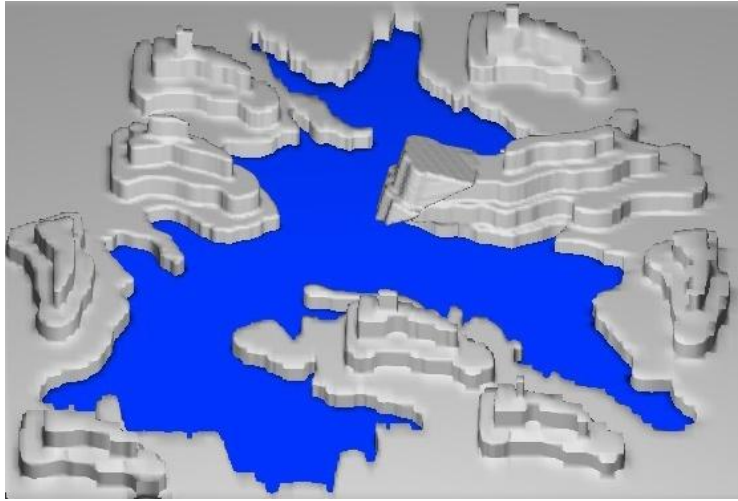
3D views of land sliding at  $t=0$ ,  $t=0.2$ ,  $t=0.4$ ,  $t=0.6$ ,  $t=0.8$ ,  $t=1$ ,  $t=2$ ,  $t=3$ ,  $t=4$  and  $t=5$  seconds for subaerial landslide is shown in Figure 5.22.



$t=0$  sec.

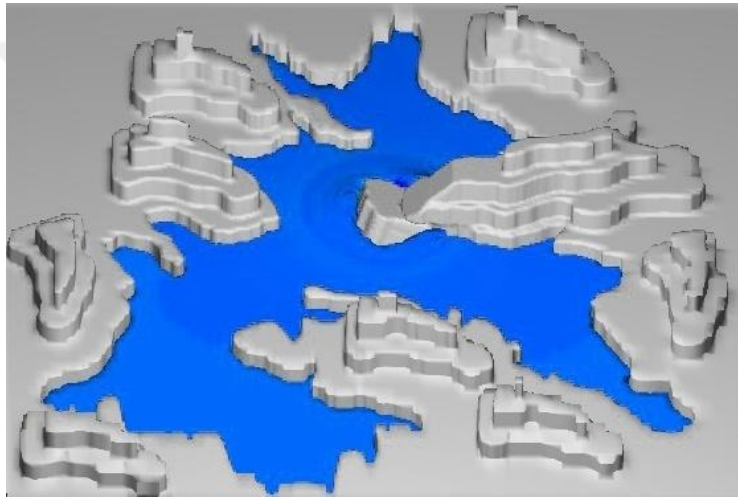
(a)

**Figure 5.22 :** 3D views of land sliding for subaerial landslide at different times: (a)  $t=0.0$  sec., (b)  $t=1.0$  sec., (c)  $t=2.0$  sec., (d)  $t=3.0$  sec., (e)  $t=4.0$  sec., (f)  $t=5.0$  sec., (g)  $t=6.0$  sec., (h)  $t=7.0$  sec., (i)  $t=8.0$  sec., (j)  $t=9.0$  sec.



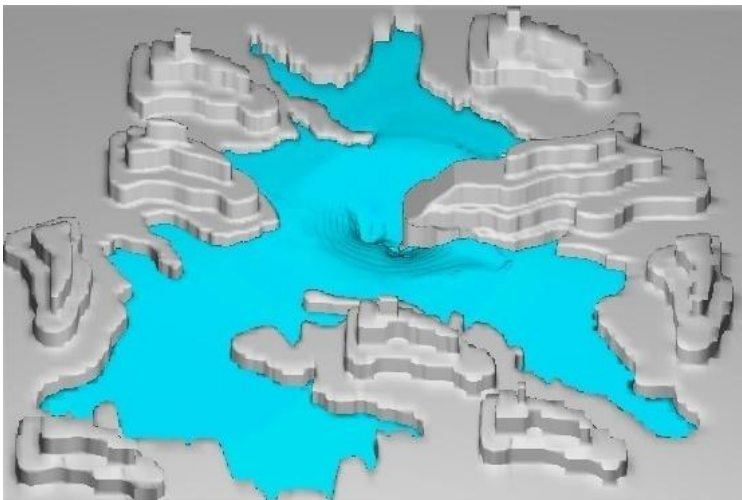
t=0.2 sec.

(b)



t=0.4 sec.

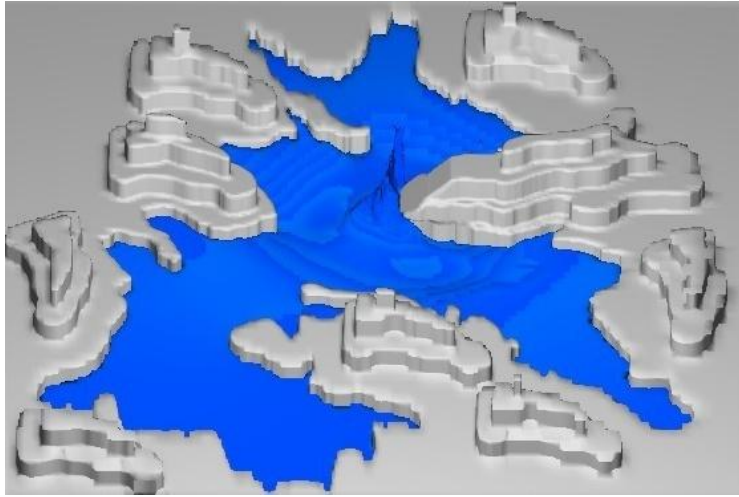
(c)



t=0.6 sec.

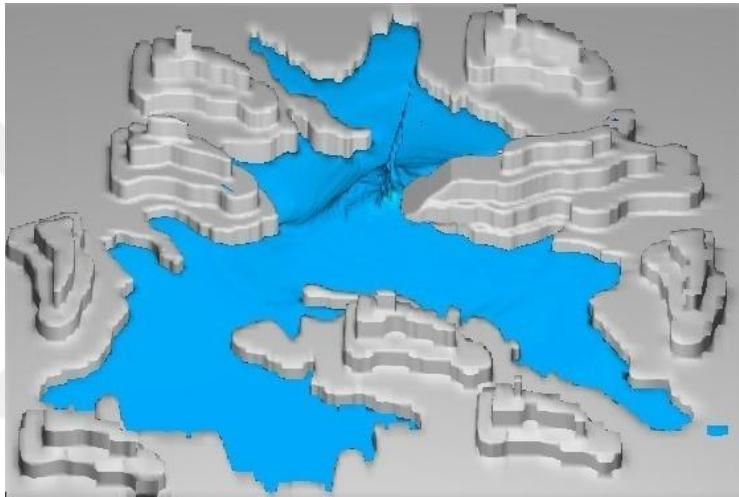
(d)

**Figure 5.22 (continued)** : 3D views of land sliding for subaerial landslide at different times: (a) t=0.0 sec., (b) t=0.2 sec., (c) t=0.4 sec., (d) t=0.6 sec., (e) t=0.8 sec., (f) t=1.0 sec., (g) t=2.0 sec., (h) t=3.0 sec., (i) t=4.0 sec., (j) t=5.0 sec.



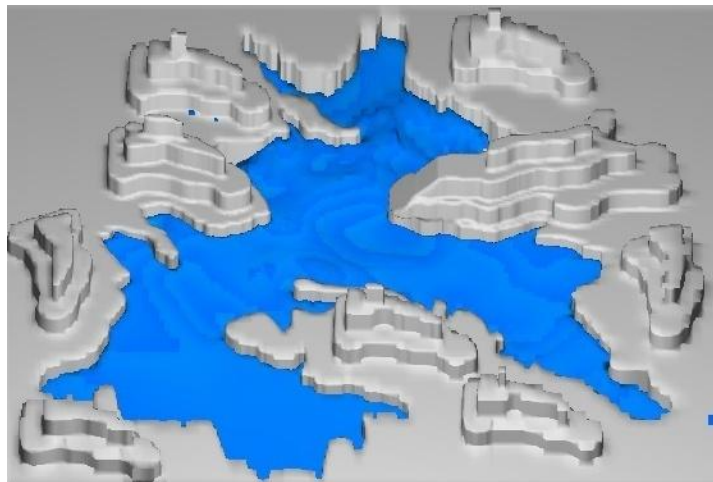
t=0.8 sec.

(e)



t=1.0 sec.

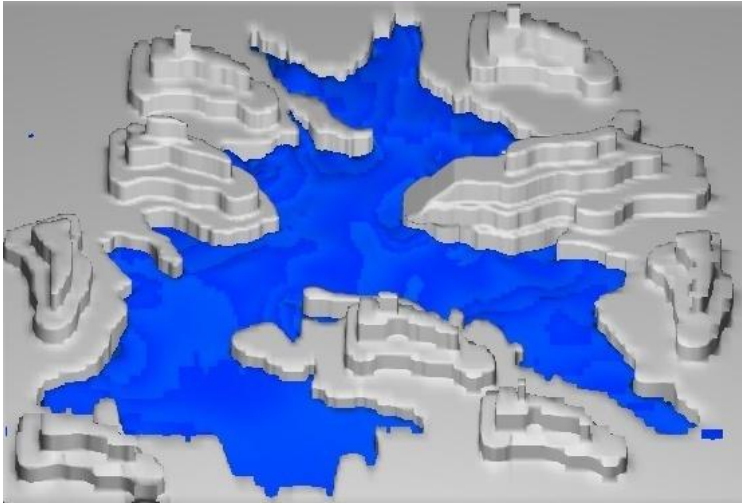
(f)



t=2.0 sec.

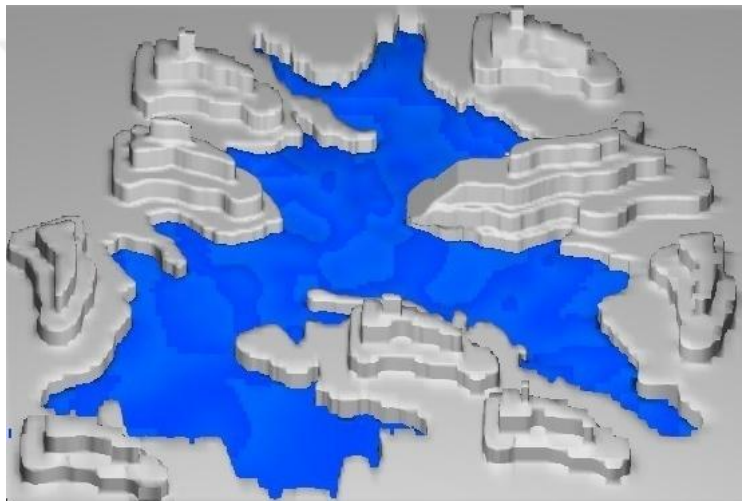
(g)

**Figure 5.22 (continued)** : 3D views of land sliding for subaerial landslide at different times: (a) t=0.0 sec., (b) t=1.0 sec., (c) t=2.0 sec., (d) t=3.0 sec., (e) t=4.0 sec., (f) t=5.0 sec., (g) t=6.0 sec., (h) t=7.0 sec., (i) t=8.0 sec., (j) t=9.0 sec.



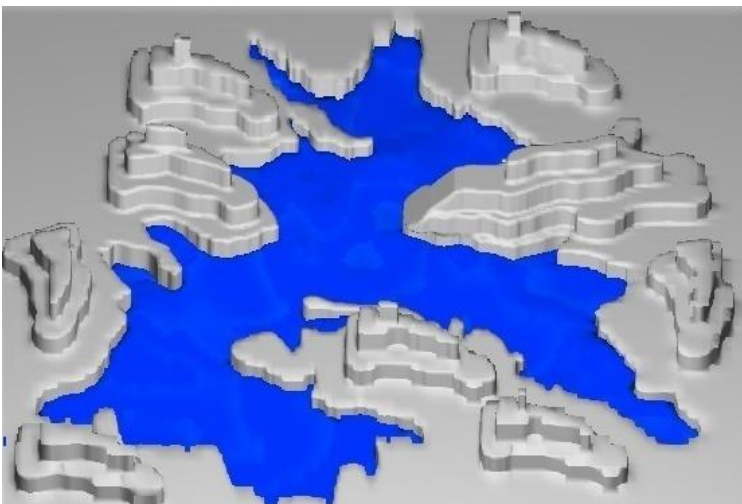
t=3.0 sec.

(h)



t=4.0 sec.

(i)



t=5.0 sec.

(j)

**Figure 5.22 (continued)** : 3D views of land sliding for subaerial landslide at different times: (a) t=0.0 sec., (b) t=1.0 sec., (c) t=2.0 sec., (d) t=3.0 sec., (e) t=4.0 sec., (f) t=5.0 sec., (g) t=6.0 sec., (h) t=7.0 sec., (i) t=8.0 sec., (j) t=9.0 sec.

The numerical results of wave amplitudes over time in locations of  $x=158\text{m}$  (cross section A-A) for subaerial landslide are presented in Figure 5.23. It shows the wave amplitude and time histories of free surface elevation for 20 seconds.

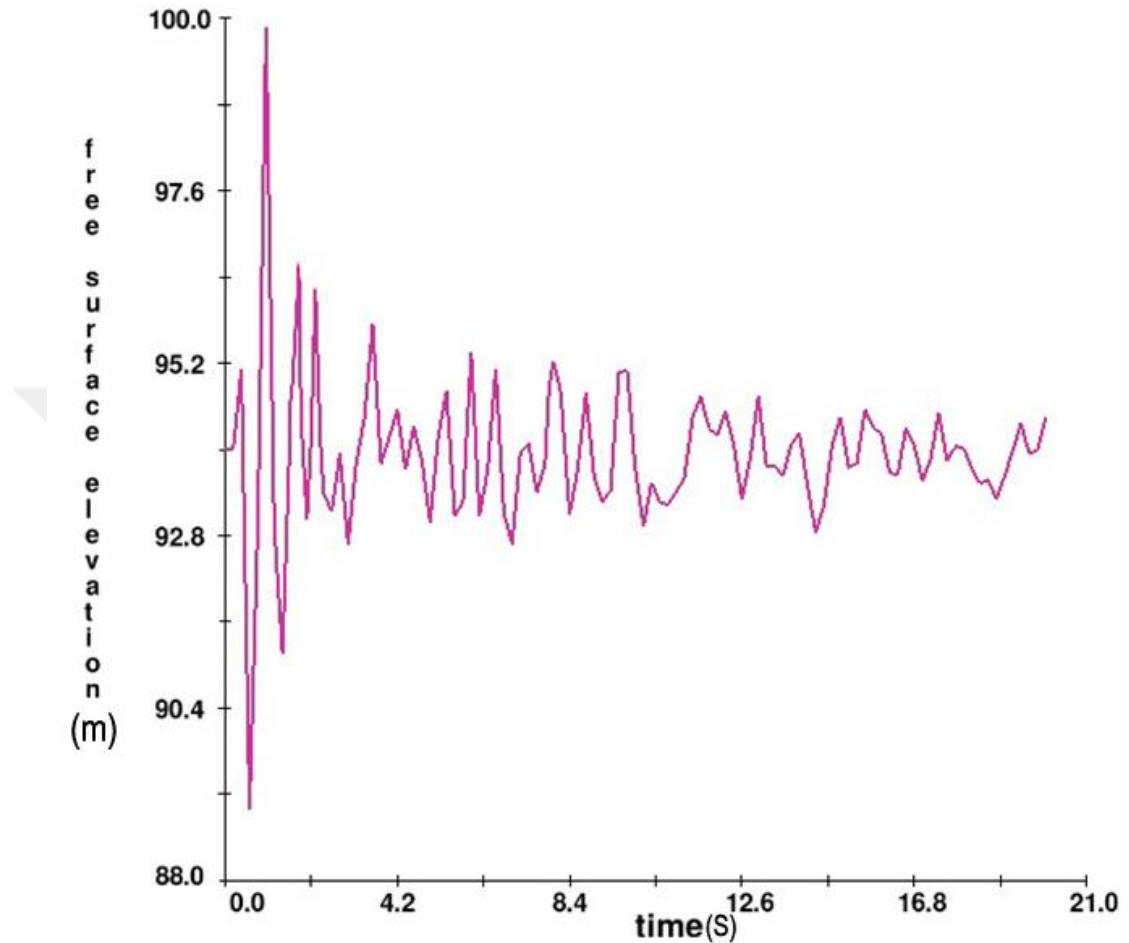


**Figure 5.23 :** Time histories of free surface elevation at  $x=158\text{ m}$  (cross section A-A) obtained from Flow-3D models



## 6. CONCLUSIONS

In this thesis, the effects of the main parameters such as slide geometry, shape (circular, rectangular and triangular) and deformation (rigid or deformable) on the impulse wave characteristics were inspected. The numerical analyses were performed in a small dimension and real case to simulate the wave generation and propagation due to subaerial and submarine landslides. Different types of landslide geometries were used to analyze the flow field.

The simulated results indicate the complex flow patterns in the lake in terms of velocity field, and free surface profiles. The numerical results of wave amplitudes and velocity magnitudes for circular, rectangular and triangular landslide geometries were applied to the sliding materials computed, which were used by geotechnical engineers to study the stabilization of the slope and slides. Based on obtained results, the following conclusions can be drawn:

Circular landslide behavior was compared with rectangular and triangular shapes during wave propagation; hence, it was expected that the wave amplitude had the highest and lowest values in triangular and circular shapes, respectively.

It is illustrated that the circular shape had the lowest value of wave amplitude, and triangular shape had the highest wave amplitude during this modeling and triangular landslide had the most absolute values of horizontal and vertical forces during and after the initial wave generation.

The results of numerical analyses demonstrate that the general pattern of wave in all cases is the same but the amplitude and period are different. The numerical analyses show that the maximum wave crest amplitude in subaerial induced waves was strongly affected by deformation and by landslide shape.

Slide deformation made a maximum reduction on wave crest amplitude down to 34% and a maximum increase up to 30% in period, although no strong changes in general pattern of subaerial impulse wave features. Slide shape did not strongly affect the general feature of impulse wave and at most the amplitude and period were changed less than 10%. Finally, the results of the Navier-Stokes model show that waves

generated were highly dependent upon the details of slide mechanism and kinematics.

The model extended for simulating impulsive waves was caused by subaerial landslides entering a water body. A set of three-dimensional experimental data was used to validate the extended model. The time phase differences and the estimation error of the wave amplitudes were less than 14% and 5%, respectively.

Therefore, the extended model is able to simulate subaerial landslide generated waves with a degree of accuracy similar to that observed for the simulated submarine landslide generated waves in generation and propagation stages.

The extended model was applied for simulating real case, the Maku Dam reservoirs located in the northwestern of Iran. The generated wave heights, wave run-up, maximum wave height were evaluated for each case.

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## **APPENDICES**

### **APPENDIX A: Tables**



## APPENDIX A

**Table A.1:** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |       | Water Surface Elevation (m) | Time (s) |
|------------------------|------|-------|-----------------------------|----------|
| u                      | v    | w     |                             |          |
| 0                      | 0    | 0     | 94                          | 0.0      |
| 0                      | 0    | 0     | 94                          | 0.0      |
| 0                      | 0    | 0     | 94                          | 0.1      |
| 0                      | 0    | 0     | 94                          | 0.1      |
| 0                      | 0    | 0     | 94                          | 0.2      |
| -0.5                   | -0.1 | 0     | 94                          | 0.2      |
| -5.6                   | -1.2 | -0.2  | 94.2                        | 0.2      |
| -21.5                  | -5   | 2.7   | 94.9                        | 0.3      |
| -31.4                  | -9.4 | 23.4  | 96.4                        | 0.3      |
| -7.9                   | 14.2 | -11   | 95.8                        | 0.4      |
| 38.1                   | 6.6  | -52.4 | 93.4                        | 0.4      |
| 41                     | 11.4 | -63.1 | 91.1                        | 0.5      |
| 38                     | 9    | -11.3 | 89.8                        | 0.5      |
| 31.7                   | 8.4  | 1.4   | 89.9                        | 0.6      |
| 25.1                   | 7.1  | 7.4   | 90.8                        | 0.6      |
| 19.6                   | 5.8  | 9.8   | 92.1                        | 0.6      |
| 14.7                   | 4.5  | 9.9   | 93.9                        | 0.7      |
| 6.7                    | 2.5  | 5.8   | 97.6                        | 0.7      |
| 3.1                    | 1.3  | 2.6   | 97                          | 0.8      |
| -0.3                   | 0.3  | -1.5  | 96.2                        | 0.8      |
| -2.9                   | -0.2 | -5.9  | 95.6                        | 0.9      |
| -4.2                   | -0.5 | -8.1  | 94.9                        | 0.9      |
| -4                     | -1   | -8.9  | 94.2                        | 1.0      |
| -2.3                   | -1.8 | -8    | 93.7                        | 1.0      |
| 0.5                    | -1   | -5.3  | 93.4                        | 1.0      |
| 3.7                    | 0.3  | -2.9  | 93.3                        | 1.1      |
| 5.5                    | 0.9  | -1.2  | 93.2                        | 1.1      |
| 6.2                    | 0.9  | 0.8   | 92.9                        | 1.2      |
| 5.9                    | 0.9  | 2.3   | 93                          | 1.2      |
| 5.2                    | 1    | 3.4   | 93.4                        | 1.2      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 4.2                    | 1.3  | 4    | 93.7                        | 1.3      |
| 3.1                    | 1.8  | 4.2  | 94                          | 1.3      |
| 2                      | 2.4  | 3.7  | 94.3                        | 1.4      |
| 1.1                    | 3.1  | 2.5  | 94.5                        | 1.4      |
| 0.8                    | 3.3  | 2.8  | 94.7                        | 1.4      |
| 0.6                    | 3.8  | 1.5  | 94.8                        | 1.5      |
| 0.7                    | 4.1  | 0.5  | 94.7                        | 1.5      |
| 0.8                    | 4.3  | -0.7 | 94.5                        | 1.6      |
| 1.1                    | 4.4  | -0.9 | 94.3                        | 1.6      |
| 1.1                    | 4.4  | -1.6 | 94.3                        | 1.6      |
| 0.8                    | 4.1  | -1.8 | 94.4                        | 1.7      |
| 0.7                    | 3.4  | -1.6 | 94.4                        | 1.7      |
| 0.5                    | 2.4  | -1.8 | 94.2                        | 1.8      |
| 0.4                    | 1.3  | -1.7 | 93.9                        | 1.8      |
| 0.6                    | 0    | -1   | 93.7                        | 1.8      |
| 1                      | -1.2 | 0    | 93.5                        | 1.9      |
| 1.8                    | -1.9 | 0.8  | 93.6                        | 1.9      |
| 2.6                    | -2.2 | 1.5  | 93.8                        | 2.0      |
| 3.2                    | -2   | 1.5  | 94.1                        | 2.0      |
| 3.4                    | -1.3 | 1.5  | 94.2                        | 2.0      |
| 3.3                    | -0.1 | 0.9  | 94.4                        | 2.1      |
| 2.8                    | 1.5  | 0.4  | 94.5                        | 2.1      |
| 2.2                    | 3.1  | -0.3 | 94.5                        | 2.2      |
| 1.5                    | 4.6  | -1.5 | 94.6                        | 2.2      |
| 0.9                    | 5.6  | -2.5 | 94.6                        | 2.2      |
| 0.2                    | 5.9  | -3.2 | 94.1                        | 2.3      |
| -0.3                   | 5.5  | -3.3 | 93.6                        | 2.3      |
| -0.7                   | 4.6  | -2.2 | 93.2                        | 2.4      |
| -0.7                   | 3.7  | -0.2 | 93                          | 2.4      |
| -0.6                   | 3    | 1.9  | 93.1                        | 2.4      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.1                   | 2.6 | 3.6  | 93.3                        | 2.5      |
| 0.6                    | 2.4 | 4.4  | 93.7                        | 2.5      |
| 1.2                    | 2.5 | 4.5  | 94.2                        | 2.6      |
| 1.7                    | 2.6 | 3.7  | 94.7                        | 2.6      |
| 2                      | 2.8 | 2.4  | 95                          | 2.6      |
| 2                      | 2.9 | 0    | 95.2                        | 2.7      |
| 1.9                    | 3   | -0.8 | 95.1                        | 2.7      |
| 1.6                    | 2.9 | -2.4 | 94.8                        | 2.8      |
| 1.2                    | 2.7 | -3.6 | 94.4                        | 2.8      |
| 0.8                    | 2.4 | -4.1 | 94                          | 2.8      |
| 0.4                    | 2.1 | -3.5 | 93.6                        | 2.9      |
| 0.1                    | 1.8 | -2.5 | 93.3                        | 2.9      |
| 0.1                    | 1.7 | -0.9 | 93.1                        | 3.0      |
| 0.5                    | 1.6 | 1.1  | 93                          | 3.0      |
| 1.2                    | 1.6 | 2.7  | 93.2                        | 3.0      |
| 2.2                    | 1.8 | 3.8  | 93.5                        | 3.1      |
| 3.1                    | 1.8 | 4.3  | 94                          | 3.1      |
| 3.6                    | 1.9 | 3.7  | 94.4                        | 3.2      |
| 3.9                    | 1.9 | 3.2  | 94.8                        | 3.2      |
| 3.6                    | 1.9 | 1.9  | 94.9                        | 3.2      |
| 2.9                    | 1.9 | 0.2  | 94.9                        | 3.3      |
| 2.1                    | 1.7 | -0.8 | 94.7                        | 3.3      |
| 1                      | 1.5 | -1.8 | 94.5                        | 3.4      |
| -0.1                   | 1.3 | -2.3 | 94.2                        | 3.4      |
| -1.2                   | 1   | -2.4 | 94                          | 3.4      |
| -2                     | 0.7 | -1.7 | 93.7                        | 3.5      |
| -2.2                   | 0.6 | -1.2 | 93.5                        | 3.5      |
| -1                     | 0.5 | -0.2 | 93.4                        | 3.6      |
| -0.9                   | 0.5 | 0.6  | 93.5                        | 3.6      |
| 0.2                    | 0.6 | 1.2  | 93.8                        | 3.6      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 1.3                    | 0.6 | 1.5  | 94.1                        | 3.7      |
| 2.1                    | 0.6 | 1.6  | 94.2                        | 3.7      |
| 2.5                    | 0.7 | 1.4  | 94.2                        | 3.8      |
| 2.6                    | 0.8 | 1.1  | 94                          | 3.8      |
| 2.3                    | 1   | 0.9  | 94.1                        | 3.8      |
| 1.9                    | 1.1 | 0.7  | 94.1                        | 3.9      |
| 1.3                    | 1.3 | 0.6  | 94.1                        | 3.9      |
| 0.8                    | 1.3 | 0.3  | 94.3                        | 4.0      |
| 0.3                    | 1.4 | -0.2 | 94.4                        | 4.0      |
| 0                      | 1.3 | -0.6 | 94.3                        | 4.0      |
| -0.1                   | 1.1 | -0.8 | 94.2                        | 4.1      |
| 0                      | 1   | -1   | 94                          | 4.1      |
| 0.2                    | 0.8 | -1   | 93.9                        | 4.2      |
| 0.6                    | 0.7 | -0.8 | 93.9                        | 4.2      |
| 0.9                    | 0.6 | -0.2 | 93.8                        | 4.2      |
| 1.2                    | 0.5 | 0.1  | 93.6                        | 4.3      |
| 1.4                    | 0.4 | 1.3  | 93.6                        | 4.3      |
| 1.5                    | 0.3 | 1.8  | 93.8                        | 4.4      |
| 1.4                    | 0.3 | 2.3  | 94                          | 4.4      |
| 1.2                    | 0.2 | 2.3  | 94.2                        | 4.4      |
| 0.9                    | 0.2 | 1.9  | 94.4                        | 4.5      |
| 0.6                    | 0.2 | 1    | 94.6                        | 4.5      |
| 0.3                    | 0.4 | 0    | 94.7                        | 4.6      |
| 0                      | 0.6 | -1.1 | 94.7                        | 4.6      |
| -0.2                   | 1   | -2.1 | 94.7                        | 4.6      |
| -0.3                   | 1.3 | -2.9 | 94.4                        | 4.7      |
| -0.4                   | 1.7 | -3.3 | 93.9                        | 4.7      |
| -0.3                   | 1.9 | -3   | 93.5                        | 4.8      |
| -0.2                   | 2.1 | -1.9 | 93.2                        | 4.8      |
| -0.1                   | 2.1 | -0.5 | 93.2                        | 4.8      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.1                    | 1.8  | 1.1  | 93.2                        | 4.9      |
| 0.4                    | 1.3  | 2.6  | 93.3                        | 4.9      |
| 0.8                    | 0.6  | 3.8  | 93.4                        | 5.0      |
| 1.1                    | 0    | 4.3  | 93.8                        | 5.0      |
| 1.3                    | -0.5 | 4.2  | 94.3                        | 5.0      |
| 1.3                    | -0.8 | 3.3  | 94.7                        | 5.1      |
| 0.9                    | -0.8 | 2.1  | 95.1                        | 5.1      |
| 0.3                    | -0.6 | 0.4  | 95.2                        | 5.2      |
| -0.4                   | -0.2 | -1.2 | 95                          | 5.2      |
| -1.3                   | 0.4  | -2.6 | 94.7                        | 5.2      |
| -2                     | 1    | -3.4 | 94.3                        | 5.3      |
| -2.6                   | 1.5  | -4   | 94                          | 5.3      |
| -2.9                   | 1.8  | -3.6 | 93.6                        | 5.4      |
| -2.7                   | 1.7  | -2.9 | 93.3                        | 5.4      |
| -2                     | 1.5  | -1.5 | 93.1                        | 5.4      |
| -0.8                   | 1    | 0.1  | 93.1                        | 5.5      |
| 0.5                    | 0.7  | 1.5  | 93.3                        | 5.5      |
| 1.8                    | 0.4  | 2.5  | 93.5                        | 5.6      |
| 2.9                    | 0.4  | 3    | 93.7                        | 5.6      |
| 3.4                    | 0.6  | 2.9  | 94                          | 5.6      |
| 3.4                    | 0.9  | 2.4  | 94.2                        | 5.7      |
| 2.8                    | 1.2  | 1.9  | 94.4                        | 5.7      |
| 1.8                    | 1.5  | 1.1  | 94.4                        | 5.8      |
| 0.6                    | 1.6  | 0.2  | 94.3                        | 5.8      |
| -0.7                   | 1.5  | -0.3 | 94.2                        | 5.8      |
| -2                     | 1.3  | -0.7 | 94.1                        | 5.9      |
| -3.1                   | 1.1  | -1   | 94                          | 5.9      |
| -3.9                   | 0.8  | -1   | 93.9                        | 6.0      |
| -4.2                   | 0.5  | -0.9 | 93.9                        | 6.0      |
| -3.9                   | 0.3  | -0.7 | 93.2                        | 6.0      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -2.9                   | 0    | -0.3 | 93.7                        | 6.1      |
| -1.4                   | -0.1 | 0.1  | 93.6                        | 6.1      |
| 0.2                    | -0.1 | 0.6  | 93.6                        | 6.2      |
| 1.8                    | 0    | 0.9  | 93.8                        | 6.2      |
| 3                      | 0.4  | 1.3  | 93.9                        | 6.2      |
| 3.8                    | 1.1  | 1.5  | 93.9                        | 6.3      |
| 4.2                    | 1.8  | 1.8  | 93.9                        | 6.3      |
| 4.1                    | 2.4  | 1.9  | 94                          | 6.4      |
| 3.7                    | 2.8  | 1.8  | 94.1                        | 6.4      |
| 3                      | 2.9  | 1.6  | 94.2                        | 6.4      |
| 1.9                    | 2.6  | 1.1  | 94.3                        | 6.5      |
| 0.9                    | 2.2  | 0.5  | 94.4                        | 6.5      |
| -0.4                   | 1.5  | -0.2 | 94.5                        | 6.6      |
| -1.5                   | 0.6  | -1   | 94.4                        | 6.6      |
| -2.3                   | -0.4 | -1.9 | 94.3                        | 6.6      |
| -2.6                   | -1.3 | -2.5 | 94.2                        | 6.7      |
| -2.5                   | -2   | -2.2 | 94                          | 6.7      |
| -1.9                   | -2.5 | -2.8 | 93.8                        | 6.8      |
| -1.1                   | -2.6 | -2.3 | 93.5                        | 6.8      |
| 0.1                    | -2.2 | -1.2 | 93.2                        | 6.8      |
| 1.1                    | -1.4 | 0.2  | 93.1                        | 6.9      |
| 1.9                    | -0.4 | 1.5  | 93.1                        | 6.9      |
| 2.6                    | 0.8  | 2.9  | 93.3                        | 7.0      |
| 3                      | 2    | 3.7  | 93.6                        | 7.0      |
| 3.1                    | 2.9  | 3.8  | 94                          | 7.0      |
| 3                      | 3.4  | 3.3  | 94.4                        | 7.1      |
| 2.5                    | 3.6  | 2.3  | 94.6                        | 7.1      |
| 1.9                    | 3.5  | 1    | 94.8                        | 7.2      |
| 1.1                    | 3    | -0.6 | 94.8                        | 7.2      |
| 0.3                    | 2.3  | -1.7 | 94.6                        | 7.2      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 1.4  | -2.6 | 94.2                        | 7.3      |
| -1.2                   | 0.5  | -3.1 | 94                          | 7.3      |
| -1.7                   | -0.2 | -2.8 | 93.5                        | 7.4      |
| -1.9                   | -0.8 | -2   | 93.4                        | 7.4      |
| -1.9                   | -1.1 | -0.7 | 93.2                        | 7.4      |
| -1.5                   | -1.1 | 0.9  | 93.1                        | 7.5      |
| -0.9                   | -0.9 | 2.3  | 93.2                        | 7.5      |
| -0.2                   | -0.7 | 3.3  | 93.5                        | 7.6      |
| 0.5                    | -0.4 | 3.6  | 93.9                        | 7.6      |
| 1.2                    | 0    | 3.4  | 94.4                        | 7.6      |
| 1.5                    | 0.3  | 2.7  | 94.6                        | 7.7      |
| 1.7                    | 0.6  | 1.8  | 94.6                        | 7.7      |
| 1.6                    | 0.8  | 0.9  | 94.6                        | 7.8      |
| 1.4                    | 1.1  | 0    | 94.5                        | 7.8      |
| 1                      | 1.3  | -0.7 | 94.3                        | 7.8      |
| 0.6                    | 1.4  | -1   | 94.2                        | 7.9      |
| 0.3                    | 1.6  | -1.1 | 94.1                        | 7.9      |
| 0.1                    | 1.7  | -1   | 94.1                        | 8.0      |
| 0                      | 1.8  | -0.7 | 94.1                        | 8.0      |
| 0                      | 1.9  | -0.5 | 94                          | 8.0      |
| 0.3                    | 1.9  | -0.2 | 94                          | 8.1      |
| 0.6                    | 1.1  | 0.1  | 93.9                        | 8.1      |
| 0.9                    | 1.6  | 0.3  | 93.9                        | 8.2      |
| 1                      | 1.3  | 0.4  | 93.9                        | 8.2      |
| 1.1                    | 0.9  | 0.4  | 94                          | 8.2      |
| 0.9                    | 0.4  | 0.3  | 94.1                        | 8.3      |
| 0.6                    | -0.1 | 0    | 94.2                        | 8.3      |
| 0.2                    | -0.5 | -0.3 | 94.2                        | 8.4      |
| -0.2                   | -0.7 | -0.7 | 94.1                        | 8.4      |
| -0.5                   | -0.6 | -1   | 94                          | 8.4      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.8                   | -0.3 | -1   | 93.1                        | 8.5      |
| -0.8                   | 0.2  | 0    | 93.7                        | 8.5      |
| -0.8                   | 0.8  | -0.4 | 93.6                        | 8.6      |
| -0.6                   | 1.5  | 0.2  | 93.6                        | 8.6      |
| -0.4                   | 2.1  | 0.9  | 93.6                        | 8.6      |
| -0.2                   | 2.6  | 1.4  | 93.7                        | 8.7      |
| 0                      | 2.9  | 1.9  | 93.8                        | 8.7      |
| 0.1                    | 3    | 2.1  | 93.9                        | 8.8      |
| 0.1                    | 2    | 2    | 94.1                        | 8.8      |
| 0.1                    | 2.4  | 1.8  | 94.3                        | 8.8      |
| 0                      | 1.8  | 1.3  | 94.4                        | 8.9      |
| -0.2                   | 1.1  | 0.7  | 94.4                        | 8.9      |
| -0.4                   | 0.5  | 0    | 94.4                        | 9.0      |
| -0.6                   | 0    | -0.6 | 94.4                        | 9.0      |
| -0.8                   | -0.5 | -1.1 | 94.3                        | 9.0      |
| -0.9                   | -0.8 | -1.5 | 94.1                        | 9.1      |
| -1                     | -0.9 | -1.6 | 94                          | 9.1      |
| -0.9                   | -0.8 | -1.6 | 93.9                        | 9.2      |
| -0.8                   | -0.6 | -1.4 | 93.8                        | 9.2      |
| -0.6                   | -0.4 | -1.1 | 93.7                        | 9.2      |
| -0.3                   | -0.1 | -0.7 | 93.7                        | 9.3      |
| 0                      | 0.1  | -0.3 | 93.7                        | 9.3      |
| 0.3                    | 0.3  | 0.2  | 93.6                        | 9.4      |
| 0.6                    | 0.3  | 0.8  | 93.6                        | 9.4      |
| 0.8                    | 0.3  | 1.4  | 93.6                        | 9.4      |
| 0.8                    | 0.2  | 1.8  | 93.7                        | 9.5      |
| 0.8                    | 0.1  | 2.2  | 93.8                        | 9.5      |
| 0.6                    | 0    | 2.3  | 94                          | 9.6      |
| 0.3                    | 0    | 2.2  | 94.2                        | 9.6      |
| 0                      | 0    | 1.7  | 94.4                        | 9.6      |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 0.1  | 1    | 94.5                        | 9.7      |
| -0.8                   | 0.2  | 0.3  | 94.6                        | 9.7      |
| -1                     | 0.2  | -0.5 | 94.5                        | 9.8      |
| -1                     | 0.3  | -1.3 | 94.4                        | 9.8      |
| -0.8                   | 0.2  | -2   | 94.3                        | 9.8      |
| -0.5                   | 0.1  | -2.3 | 94.1                        | 9.9      |
| 0                      | -0.1 | -2.4 | 94                          | 9.9      |
| 0.1                    | 1.3  | -0.9 | 94                          | 10.0     |
| 0.2                    | 1.4  | -0.9 | 93.9                        | 10.0     |
| 0.4                    | 1.4  | -0.8 | 93.8                        | 10.0     |
| 0.5                    | 1.4  | -0.6 | 93.8                        | 10.1     |
| 0.7                    | 1.3  | -0.3 | 93.8                        | 10.1     |
| 0.7                    | 1.1  | 0.1  | 93.8                        | 10.2     |
| 0.7                    | 0.9  | 0.4  | 93.8                        | 10.2     |
| 0.6                    | 0.6  | 0.6  | 93.9                        | 10.2     |
| 0.3                    | 0.4  | 0.7  | 93.9                        | 10.3     |
| 0                      | 0.3  | 0.7  | 94                          | 10.3     |
| -0.4                   | 0.2  | 0.5  | 94.1                        | 10.4     |
| -0.8                   | 0.3  | 0.3  | 94.1                        | 10.4     |
| -1.1                   | 0.4  | 0.1  | 94.1                        | 10.4     |
| -1.4                   | 0.7  | -0.2 | 94.1                        | 10.5     |
| -1.5                   | 0.9  | -0.4 | 94.1                        | 10.5     |
| -1.4                   | 1.2  | -0.6 | 94.1                        | 10.6     |
| -1.1                   | 1.5  | -0.6 | 94                          | 10.6     |
| -0.1                   | 1.6  | -0.5 | 93.9                        | 10.6     |
| -0.4                   | 1.8  | -0.3 | 93.9                        | 10.7     |
| 0.1                    | 1.8  | 0    | 93.9                        | 10.7     |
| 0.5                    | 1.7  | 0.2  | 93.9                        | 10.8     |
| 0.8                    | 1.6  | 0.4  | 94                          | 10.8     |
| 1                      | 1.3  | 0.4  | 94                          | 10.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 1                      | 1.1  | 0.4  | 94.1                        | 10.9     |
| 0.8                    | 0.8  | 0.2  | 94.2                        | 10.9     |
| 0.5                    | 0.5  | -0.1 | 94.2                        | 21.0     |
| 0                      | 0.3  | -0.4 | 94.2                        | 21.0     |
| -0.5                   | 0.1  | -0.6 | 94.1                        | 21.0     |
| -1                     | -0.1 | -0.8 | 94.1                        | 21.1     |
| -1.6                   | -0.2 | -0.8 | 94                          | 21.1     |
| -1.9                   | -0.2 | -0.8 | 93.9                        | 21.2     |
| -2.1                   | -0.2 | -0.6 | 93.9                        | 21.2     |
| -2.1                   | -0.2 | -0.4 | 93.9                        | 21.2     |
| -1.9                   | -0.2 | -0.2 | 93.9                        | 21.3     |
| -1.4                   | -0.2 | 0.1  | 93.9                        | 21.3     |
| -0.9                   | -0.2 | 0.4  | 93.9                        | 21.4     |
| -0.3                   | -0.2 | 0.6  | 93.9                        | 21.4     |
| 0.1                    | -0.2 | 0.9  | 93.9                        | 21.4     |
| 0.6                    | -0.2 | 1    | 94                          | 21.5     |
| 0.9                    | -0.2 | 1.1  | 94.1                        | 21.5     |
| 1                      | -0.1 | 1    | 94.2                        | 21.6     |
| 0.9                    | 0    | 0.7  | 94.3                        | 21.6     |
| 0.6                    | 0.1  | 0.2  | 94.4                        | 21.6     |
| 0                      | 0.3  | -0.4 | 94.4                        | 21.7     |
| -0.5                   | 0.5  | -1.1 | 94.4                        | 21.7     |
| -1.1                   | 0.6  | -1.7 | 94.3                        | 21.8     |
| -1.7                   | 0.8  | -2.2 | 94.2                        | 21.8     |
| -2                     | 0.8  | -2.5 | 94                          | 21.8     |
| -2.1                   | 0.7  | -2.4 | 93.8                        | 21.9     |
| -2                     | 0.6  | -2.2 | 93.6                        | 21.9     |
| -1.7                   | 0.5  | -1.6 | 93.5                        | 22.0     |
| -1                     | 0.2  | -0.7 | 93.4                        | 22.0     |
| -0.4                   | 0    | 0.1  | 93.4                        | 22.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.4                    | -0.2 | 0.9  | 93.5                        | 22.1     |
| 1.1                    | -0.3 | 1.5  | 93.6                        | 22.1     |
| 1.5                    | -0.3 | 1.9  | 93.7                        | 22.2     |
| 1.6                    | -0.3 | 2    | 93.8                        | 22.2     |
| 1.7                    | -0.1 | 1.9  | 94                          | 22.2     |
| 1.4                    | 0.1  | 1.5  | 94.2                        | 22.3     |
| 1.1                    | 0.3  | 1    | 94.3                        | 22.3     |
| 0.5                    | 0.5  | 0.3  | 94.3                        | 22.4     |
| 0                      | 0.7  | -0.4 | 94.3                        | 22.4     |
| -0.6                   | 0.8  | -1.1 | 94.3                        | 22.4     |
| -1.1                   | 0.8  | -1.5 | 94.1                        | 22.5     |
| -1.4                   | 0.8  | -1.8 | 94                          | 22.5     |
| -1.5                   | 0.7  | -1.7 | 93.8                        | 22.6     |
| -1.5                   | 0.7  | -1.5 | 93.7                        | 22.6     |
| -1.4                   | 0.6  | -1   | 93.6                        | 22.6     |
| -1.1                   | 0.6  | -0.5 | 93.6                        | 22.7     |
| -0.7                   | 0.6  | 0.2  | 93.6                        | 22.7     |
| -0.2                   | 0.6  | 0.8  | 93.6                        | 22.8     |
| 0.1                    | 0.6  | 1.2  | 93.7                        | 22.8     |
| 0.4                    | 0.6  | 1.4  | 93.9                        | 22.8     |
| 0.5                    | 0.6  | 1.5  | 94                          | 22.9     |
| 0.5                    | 0.6  | 1.2  | 94.1                        | 22.9     |
| 0.4                    | 0.6  | 0.8  | 94.2                        | 23.0     |
| 0.2                    | 0.6  | 0.2  | 94.3                        | 23.0     |
| 0                      | 0.6  | -0.4 | 94.3                        | 23.0     |
| -0.2                   | 0.7  | -0.9 | 94.2                        | 23.1     |
| -0.3                   | 0.8  | -1.2 | 94.1                        | 23.1     |
| -0.4                   | 0.9  | -1.4 | 94                          | 23.2     |
| -0.4                   | 1    | -1.2 | 93.8                        | 23.2     |
| -0.2                   | 1    | -1   | 93.7                        | 23.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.1                   | 1.1  | -0.7 | 93.7                        | 23.3     |
| 0.2                    | 1    | -0.2 | 93.7                        | 23.3     |
| 0.4                    | 1    | 0.2  | 93.8                        | 23.4     |
| 0.6                    | 0.9  | 0.5  | 93.9                        | 23.4     |
| 0.7                    | 0.9  | 0.6  | 93.9                        | 23.4     |
| 0.8                    | 0.9  | 0.6  | 94                          | 23.5     |
| 0.7                    | 1    | 0.6  | 94                          | 23.5     |
| 0.6                    | 1.1  | 0.3  | 94.1                        | 23.6     |
| 0.4                    | 1.2  | 0.1  | 94.1                        | 23.6     |
| 0.1                    | 1.4  | -0.2 | 94.1                        | 23.6     |
| -0.1                   | 1.6  | -0.6 | 94.1                        | 23.7     |
| -0.3                   | 1.7  | -0.8 | 94.1                        | 23.7     |
| -0.4                   | 1.8  | -0.9 | 94                          | 23.8     |
| -0.5                   | 1.9  | -0.9 | 93.9                        | 23.8     |
| -0.5                   | 1.9  | -0.7 | 93.8                        | 23.8     |
| -0.4                   | 1.9  | -0.4 | 93.8                        | 23.9     |
| -0.3                   | 1.8  | 0    | 93.8                        | 23.9     |
| -0.2                   | 1.7  | 0.3  | 93.8                        | 24.0     |
| -0.1                   | 1.6  | 0.7  | 93.9                        | 24.0     |
| 0.1                    | 1.4  | 0.9  | 93.9                        | 24.0     |
| 0.2                    | 1.2  | 1    | 94                          | 24.1     |
| 0.4                    | 1.1  | 1    | 94.1                        | 24.1     |
| 0.5                    | 0.9  | 0.8  | 94.2                        | 24.2     |
| 0.6                    | 0.7  | 0.5  | 94.3                        | 24.2     |
| 0.6                    | 0.5  | 0.1  | 94.3                        | 24.2     |
| 0.6                    | 0.3  | -0.5 | 94.3                        | 24.3     |
| 0.5                    | 0.2  | -0.9 | 94.3                        | 24.3     |
| 0.3                    | 0.1  | -1.2 | 94.2                        | 24.4     |
| 0.1                    | 0    | -1.5 | 94.1                        | 24.4     |
| -0.2                   | -0.2 | -1.5 | 94                          | 24.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.4                   | -0.3 | -1.4 | 93.9                        | 24.5     |
| -0.5                   | -0.3 | -1.1 | 93.6                        | 24.5     |
| -0.6                   | -0.4 | -0.8 | 93.8                        | 24.6     |
| -0.6                   | -0.4 | -0.3 | 93.7                        | 24.6     |
| -0.5                   | -0.4 | 0.2  | 93.7                        | 24.6     |
| -0.3                   | -0.3 | 0.5  | 93.8                        | 24.7     |
| -0.1                   | -0.1 | 0.8  | 93.9                        | 24.7     |
| 0                      | 0.1  | 0.9  | 94                          | 24.8     |
| 0.2                    | 0.4  | 0.9  | 94.1                        | 24.8     |
| 0.2                    | 0.7  | 0.6  | 94.2                        | 24.8     |
| 0                      | 0.9  | 0.2  | 94.2                        | 24.9     |
| -0.2                   | 1    | -0.2 | 94.2                        | 24.9     |
| -0.5                   | 1    | -0.6 | 94.2                        | 25.0     |
| -0.8                   | 0.9  | -1   | 94.1                        | 25.0     |
| -1.2                   | 0.6  | -1.2 | 94                          | 25.0     |
| -1.4                   | 0.3  | -1.4 | 94                          | 25.1     |
| -1.5                   | 0    | -1.3 | 93.9                        | 25.1     |
| -1.5                   | -0.3 | -1.1 | 93.8                        | 25.2     |
| -1.4                   | -0.5 | -0.8 | 93.8                        | 25.2     |
| -1.1                   | -0.6 | -0.4 | 93.7                        | 25.2     |
| -0.8                   | -0.5 | 0.1  | 93.7                        | 25.3     |
| -0.6                   | -0.4 | 0.5  | 93.7                        | 25.3     |
| -0.3                   | -0.2 | 0.9  | 93.8                        | 25.4     |
| -0.1                   | 0.1  | 1.2  | 93.9                        | 25.4     |
| 0.1                    | 0.3  | 1.3  | 94                          | 25.4     |
| 0.1                    | 0.5  | 1.2  | 94.1                        | 25.5     |
| 0.1                    | 0.6  | 1    | 94.2                        | 25.5     |
| 0                      | 0.6  | 0.6  | 94.3                        | 25.6     |
| -0.1                   | 0.6  | 0.2  | 94.3                        | 25.6     |
| -0.3                   | 0.5  | -0.3 | 94.3                        | 25.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.4                   | 0.5 | -0.7 | 94.3                        | 25.7     |
| -0.5                   | 0.5 | -1.1 | 94.2                        | 25.7     |
| -0.5                   | 0.4 | -1.3 | 94.2                        | 25.8     |
| -0.5                   | 0.4 | -1.5 | 94.1                        | 25.8     |
| -0.4                   | 0.5 | -1.5 | 94                          | 25.8     |
| -0.3                   | 0.5 | -1.4 | 93.9                        | 25.9     |
| -0.2                   | 0.4 | -1.2 | 93.7                        | 25.9     |
| -0.1                   | 0.4 | -0.9 | 93.8                        | 26.0     |
| -0.1                   | 0.3 | -0.7 | 93.7                        | 26.0     |
| -0.2                   | 0.2 | -0.4 | 93.7                        | 26.0     |
| -0.2                   | 0.2 | -0.2 | 93.8                        | 26.1     |
| -0.3                   | 0.1 | -0.1 | 93.8                        | 26.1     |
| -0.4                   | 0.1 | 0    | 93.8                        | 26.2     |
| -0.5                   | 0.2 | 0.1  | 93.8                        | 26.2     |
| -0.7                   | 0.3 | 0.1  | 93.8                        | 26.2     |
| -0.7                   | 0.5 | 0    | 93.8                        | 26.3     |
| -0.8                   | 0.7 | 0.1  | 93.8                        | 26.3     |
| -0.2                   | 1   | 0.1  | 93.8                        | 26.4     |
| -0.8                   | 1.2 | 0.2  | 93.8                        | 26.4     |
| -0.7                   | 1.4 | 0.3  | 93.9                        | 26.4     |
| -0.7                   | 1.6 | 0.4  | 93.9                        | 26.5     |
| -0.6                   | 1.7 | 0.5  | 93.9                        | 26.5     |
| -0.5                   | 1.6 | 0.5  | 94                          | 26.6     |
| -0.4                   | 1.5 | 0.5  | 94                          | 26.6     |
| -0.3                   | 1.4 | 0.3  | 94.1                        | 26.6     |
| -0.3                   | 1.1 | 0    | 94.1                        | 26.7     |
| -0.3                   | 0.9 | -0.3 | 94.2                        | 26.7     |
| -0.4                   | 0.6 | -0.6 | 94.1                        | 26.8     |
| -0.5                   | 0.4 | -1   | 94.1                        | 26.8     |
| -0.6                   | 0.2 | -1.2 | 94                          | 26.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.6                   | 0.2 | -1.3 | 93.9                        | 26.9     |
| -0.6                   | 0.2 | -1.3 | 93.8                        | 26.9     |
| -0.5                   | 0.4 | -1   | 93.7                        | 27.0     |
| -0.3                   | 0.6 | -0.6 | 93.7                        | 27.0     |
| -0.1                   | 0.8 | -0.1 | 93.6                        | 27.0     |
| 0.1                    | 0.9 | 0.4  | 93.6                        | 27.1     |
| 0.3                    | 1   | 0.8  | 93.7                        | 27.1     |
| 0.5                    | 1.1 | 1.2  | 93.8                        | 27.2     |
| 0.7                    | 1   | 1.4  | 93.9                        | 27.2     |
| 0.7                    | 0.9 | 1.4  | 94.1                        | 27.2     |
| 0.7                    | 0.8 | 1.2  | 94.2                        | 27.3     |
| 0.7                    | 0.6 | 0.8  | 94.3                        | 27.3     |
| 0.5                    | 0.4 | 0.3  | 94.3                        | 27.4     |
| 0.3                    | 0.3 | -0.3 | 94.3                        | 27.4     |
| 0.1                    | 0.2 | -0.8 | 94.3                        | 27.4     |
| -0.1                   | 0.2 | -1.2 | 94.2                        | 27.5     |
| -0.2                   | 0.2 | -1.5 | 94.1                        | 27.5     |
| -0.3                   | 0.3 | -1.6 | 94                          | 27.6     |
| -0.3                   | 0.4 | -1.6 | 93.9                        | 27.6     |
| -0.3                   | 0.5 | -1.4 | 93.8                        | 27.6     |
| -0.1                   | 0.6 | -1.1 | 93.8                        | 27.7     |
| 0                      | 0.7 | -0.7 | 93.7                        | 27.7     |
| 0.2                    | 0.8 | -0.3 | 93.7                        | 27.8     |
| 0.5                    | 0.3 | 0.2  | 93.7                        | 27.8     |
| 0.6                    | 0.8 | 0.6  | 93.7                        | 27.8     |
| 0.7                    | 0.9 | 0.9  | 93.3                        | 27.9     |
| 0.7                    | 0.9 | 1    | 93.9                        | 27.9     |
| 0.6                    | 0.9 | 1    | 94                          | 28.0     |
| 0.4                    | 1   | 0.9  | 94.1                        | 28.0     |
| 0.1                    | 1   | 0.7  | 94.2                        | 28.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.2                   | 0.9  | 0.4  | 94.2                        | 28.1     |
| -0.5                   | 0.9  | 0    | 94.2                        | 28.1     |
| -0.8                   | 0.7  | -0.3 | 94.2                        | 28.2     |
| -1                     | 0.5  | -0.7 | 94.2                        | 28.2     |
| -1                     | 0.3  | -0.9 | 94.1                        | 28.2     |
| -0.9                   | 0.2  | -1.1 | 94.1                        | 28.3     |
| -0.7                   | 0.1  | -1.2 | 94                          | 28.3     |
| -0.4                   | 0    | -1.1 | 93.9                        | 28.4     |
| 0                      | 0    | -1   | 93.9                        | 28.4     |
| 0.3                    | 0    | -0.8 | 93.7                        | 28.4     |
| 0.6                    | 0.1  | -0.5 | 93.8                        | 28.5     |
| 0.8                    | 0.2  | -0.2 | 93.8                        | 28.5     |
| 0.8                    | 0.3  | 0    | 93.8                        | 28.6     |
| 0.8                    | 0.5  | 0.3  | 93.3                        | 28.6     |
| 0.5                    | 0.6  | 0.5  | 93.9                        | 28.6     |
| 0.2                    | 0.7  | 0.6  | 93.9                        | 28.7     |
| -0.2                   | 0.7  | 0.6  | 94                          | 28.7     |
| -0.6                   | 0.7  | 0.5  | 94                          | 28.8     |
| -1                     | 0.6  | 0.4  | 94.1                        | 28.8     |
| -1.3                   | 0.5  | 0.1  | 94.2                        | 28.8     |
| -1.5                   | 0.3  | -0.2 | 94.2                        | 28.9     |
| -1.5                   | 0.2  | -0.4 | 94.1                        | 28.9     |
| -1.4                   | 0.1  | -0.6 | 94.1                        | 29.0     |
| -1.1                   | 0    | -0.6 | 94                          | 29.0     |
| -0.8                   | -0.1 | -0.5 | 93.9                        | 29.0     |
| -0.4                   | 0    | -0.3 | 93.9                        | 29.1     |
| -0.1                   | 0.1  | -0.1 | 93.9                        | 29.1     |
| 0.1                    | 0.2  | 0.2  | 93.9                        | 29.2     |
| 0.3                    | 0.3  | 0.4  | 94                          | 29.2     |
| 0.3                    | 0.5  | 0.6  | 94                          | 29.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.2                    | 0.7  | 0.6  | 94.1                        | 29.3     |
| 0                      | 0.8  | 0.5  | 94.2                        | 29.3     |
| -0.3                   | 0.9  | 0.2  | 94.2                        | 29.4     |
| -0.6                   | 1    | -0.1 | 94.3                        | 29.4     |
| -0.9                   | 1    | -0.5 | 94.3                        | 29.4     |
| -1.2                   | 1.1  | -0.9 | 94.2                        | 29.5     |
| -1.4                   | 1.1  | -1.1 | 94.1                        | 29.5     |
| -1.5                   | 1.1  | -1.3 | 94                          | 29.6     |
| -1.4                   | 1.1  | -1.3 | 94                          | 29.6     |
| -1.3                   | 1.1  | -1.2 | 93.9                        | 29.6     |
| -1.1                   | 1.1  | -1   | 93.8                        | 29.7     |
| -0.8                   | 1    | -0.6 | 93.8                        | 29.7     |
| -0.5                   | 0.9  | -0.3 | 93.8                        | 29.8     |
| -0.3                   | 0.7  | 0    | 93.8                        | 29.8     |
| 0                      | 0.5  | 0.3  | 93.8                        | 29.8     |
| 0.1                    | 0.4  | 0.5  | 93.8                        | 29.9     |
| 0.2                    | 0.2  | 0.6  | 93.9                        | 29.9     |
| 0.1                    | 0    | 0.5  | 94                          | 30.0     |
| 0                      | -0.1 | 0.4  | 94                          | 30.0     |
| -0.2                   | -0.2 | 0.1  | 94.1                        | 30.0     |
| -0.5                   | -0.2 | -0.2 | 94.1                        | 30.1     |
| -0.7                   | -0.1 | -0.5 | 94.1                        | 30.1     |
| -1                     | 0.1  | -0.7 | 94                          | 30.2     |
| -1.1                   | 0.3  | -0.9 | 94                          | 30.2     |
| -1.2                   | 0.5  | -0.9 | 93.9                        | 30.2     |
| -1.1                   | 0.6  | -0.8 | 93.8                        | 30.3     |
| -1                     | 0.7  | -0.6 | 93.8                        | 30.3     |
| -0.8                   | 0.6  | -0.3 | 93.7                        | 30.4     |
| -0.5                   | 0.5  | 0    | 93.7                        | 30.4     |
| -0.3                   | 0.4  | 0.3  | 93.8                        | 30.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.1                   | 0.1  | 0.5  | 93.8                        | 30.5     |
| 0.1                    | -0.1 | 0.6  | 93.9                        | 30.5     |
| 0.1                    | -0.3 | 0.7  | 94                          | 30.6     |
| 0.1                    | -0.5 | 0.6  | 94                          | 30.6     |
| 0                      | -0.5 | 0.5  | 94                          | 30.6     |
| -0.1                   | -0.5 | 0.3  | 94.1                        | 30.7     |
| -0.3                   | -0.4 | 0    | 94.1                        | 30.7     |
| -0.5                   | -0.2 | -0.2 | 94.1                        | 30.8     |
| -0.6                   | -0.1 | -0.4 | 94.1                        | 30.8     |
| -0.7                   | 0.1  | -0.6 | 94.1                        | 30.8     |
| -0.6                   | 0.3  | -0.7 | 94                          | 30.9     |
| -0.5                   | 0.5  | -0.7 | 94                          | 30.9     |
| -0.3                   | 0.6  | -0.7 | 93.9                        | 31.0     |
| -0.1                   | 0.6  | -0.5 | 93.9                        | 31.0     |
| 0.2                    | 0.6  | -0.3 | 93.8                        | 31.0     |
| 0.3                    | 0.6  | -0.1 | 93.8                        | 31.1     |
| 0.5                    | 0.5  | 0    | 93.9                        | 31.1     |
| 0.5                    | 0.4  | 0.2  | 93.9                        | 31.2     |
| 0.5                    | 0.3  | 0.2  | 94                          | 31.2     |
| 0.3                    | 0.3  | 0.2  | 94                          | 31.2     |
| 0.1                    | 0.2  | 0.1  | 94                          | 31.3     |
| -0.1                   | 0.3  | 0    | 94                          | 31.3     |
| -0.3                   | 0.4  | -0.2 | 94                          | 31.4     |
| -0.5                   | 0.5  | -0.3 | 94                          | 31.4     |
| -0.6                   | 0.6  | -0.4 | 94                          | 31.4     |
| -0.7                   | 0.6  | -0.4 | 94                          | 31.5     |
| -0.7                   | 0.7  | -0.4 | 93.9                        | 31.5     |
| -0.5                   | 0.8  | -0.4 | 93.9                        | 31.6     |
| -0.4                   | 0.8  | -0.3 | 93.9                        | 31.6     |
| -0.2                   | 0.8  | -0.2 | 93.9                        | 31.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.1                    | 0.5 | 0    | 93.9                        | 31.7     |
| 0.3                    | 0.8 | 0.1  | 93.9                        | 31.7     |
| 0.5                    | 0.9 | 0.2  | 93.9                        | 31.8     |
| 0.6                    | 0.9 | 0.2  | 93.9                        | 31.8     |
| 0.6                    | 1   | 0.2  | 94                          | 31.8     |
| 0.6                    | 1   | 0.1  | 94                          | 31.9     |
| 0.6                    | 1   | 0    | 94.1                        | 31.9     |
| 0.5                    | 1   | -0.2 | 94.1                        | 32.0     |
| 0.4                    | 1   | -0.4 | 94.1                        | 32.0     |
| 0.3                    | 0.9 | -0.5 | 94                          | 32.0     |
| 0.2                    | 0.5 | -0.6 | 94                          | 32.1     |
| 0.1                    | 0.7 | -0.6 | 93.9                        | 32.1     |
| 0                      | 0.6 | -0.5 | 93.9                        | 32.2     |
| -0.1                   | 0.5 | -0.3 | 93.8                        | 32.2     |
| -0.1                   | 0.4 | 0    | 93.8                        | 32.2     |
| -0.1                   | 0.4 | 0.2  | 93.8                        | 32.3     |
| -0.2                   | 0.4 | 0.4  | 93.9                        | 32.3     |
| -0.2                   | 0.5 | 0.6  | 93.9                        | 32.4     |
| -0.2                   | 0.6 | 0.7  | 94                          | 32.4     |
| -0.3                   | 0.7 | 0.6  | 94.1                        | 32.4     |
| -0.3                   | 0.8 | 0.5  | 94.1                        | 32.5     |
| -0.4                   | 1   | 0.3  | 94.2                        | 32.5     |
| -0.6                   | 1.1 | 0    | 94.2                        | 32.6     |
| -0.7                   | 1.3 | -0.4 | 94.2                        | 32.6     |
| -0.8                   | 1.3 | -0.6 | 94.1                        | 32.6     |
| -0.8                   | 1.4 | -0.4 | 94.1                        | 32.7     |
| -0.9                   | 1.3 | -0.9 | 94                          | 32.7     |
| -0.8                   | 1.2 | -0.8 | 93.9                        | 32.8     |
| -0.7                   | 1   | -0.6 | 93.9                        | 32.8     |
| -0.6                   | 0.9 | -0.3 | 93.8                        | 32.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 0.6  | 0    | 93.3                        | 32.9     |
| -0.4                   | 0.4  | 0.4  | 93.8                        | 32.9     |
| -0.4                   | 0.2  | 0.8  | 93.9                        | 33.0     |
| -0.4                   | 0    | 1    | 94                          | 33.0     |
| -0.4                   | -0.2 | 1.1  | 94.1                        | 33.0     |
| -0.5                   | -0.4 | 1    | 94.2                        | 33.1     |
| -0.7                   | -0.5 | 0.8  | 94.3                        | 33.1     |
| -0.8                   | -0.6 | 0.4  | 94.3                        | 33.2     |
| -1                     | -0.6 | -0.1 | 94.4                        | 33.2     |
| -1                     | -0.5 | -0.6 | 94.3                        | 33.2     |
| -1.1                   | -0.2 | -1.1 | 94.3                        | 33.3     |
| -1                     | 0    | -1.5 | 94.2                        | 33.3     |
| -0.9                   | 0.3  | -1.6 | 94                          | 33.4     |
| -0.6                   | 0.5  | -1.5 | 93.9                        | 33.4     |
| -0.3                   | 0.7  | -1.2 | 93.8                        | 33.4     |
| 0                      | 0.9  | -0.9 | 93.7                        | 33.5     |
| 0.4                    | 0.9  | -0.4 | 93.7                        | 33.5     |
| 0.7                    | 0.8  | 0.1  | 93.7                        | 33.6     |
| 0.8                    | 0.6  | 0.5  | 93.8                        | 33.6     |
| 0.9                    | 0.4  | 0.6  | 93.9                        | 33.6     |
| 0.8                    | 0.1  | 0.7  | 94                          | 33.7     |
| 0.5                    | -0.2 | 0.6  | 94                          | 33.7     |
| 0.1                    | -0.5 | 0.3  | 94.1                        | 33.8     |
| -0.3                   | -0.7 | 0    | 94.1                        | 33.8     |
| 0                      | -0.9 | -0.4 | 94.1                        | 33.8     |
| -1.2                   | -1   | -0.7 | 94.1                        | 33.9     |
| -1.6                   | -0.9 | -1   | 94                          | 33.9     |
| -1.8                   | -0.8 | -1.1 | 94                          | 34.0     |
| -1.9                   | -0.6 | -1   | 93.8                        | 34.0     |
| -1.8                   | -0.3 | -0.4 | 93.7                        | 34.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -1.5                   | -0.1 | -0.5 | 93.6                        | 34.1     |
| -1.2                   | 0.2  | 0    | 93.6                        | 34.1     |
| -0.8                   | 0.5  | 0.5  | 93.6                        | 34.2     |
| -0.3                   | 0.6  | 1    | 93.8                        | 34.2     |
| 0                      | 0.7  | 1.3  | 93.8                        | 34.2     |
| 0.2                    | 0.7  | 1.4  | 94                          | 34.3     |
| 0.3                    | 0.6  | 1.4  | 94.1                        | 34.3     |
| 0.3                    | 0.5  | 1.1  | 94.2                        | 34.4     |
| 0                      | 0.3  | 0.6  | 94.3                        | 34.4     |
| -0.3                   | 0.2  | 0.1  | 94.3                        | 34.4     |
| -0.6                   | 0    | -0.5 | 94.3                        | 34.5     |
| -1                     | -0.1 | -1   | 94.3                        | 34.5     |
| -1.2                   | -0.2 | -1.5 | 94.2                        | 34.6     |
| -1.4                   | -0.3 | -1.8 | 94.1                        | 34.6     |
| -1.5                   | -0.3 | -1.9 | 93.9                        | 34.6     |
| -1.4                   | -0.3 | -1.8 | 93.8                        | 34.7     |
| -1.2                   | -0.3 | -1.5 | 93.7                        | 34.7     |
| -0.9                   | -0.3 | -1.1 | 93.6                        | 34.8     |
| -0.4                   | -0.2 | -0.5 | 93.5                        | 34.8     |
| 0                      | -0.1 | 0    | 93.5                        | 34.8     |
| 0.3                    | 0    | 0.6  | 93.6                        | 34.9     |
| 0.6                    | 0.1  | 1    | 93.7                        | 34.9     |
| 0.8                    | 0.2  | 1.3  | 93.8                        | 35.0     |
| 0.8                    | 0.4  | 1.4  | 93.9                        | 35.0     |
| 0.7                    | 0.5  | 1.3  | 94                          | 35.0     |
| 0.5                    | 0.7  | 1    | 94.1                        | 35.1     |
| 0.3                    | 0.9  | 0.6  | 94.2                        | 35.1     |
| 0                      | 1.1  | 0.1  | 94.2                        | 35.2     |
| -0.2                   | 1.2  | -0.3 | 94.2                        | 35.2     |
| -0.4                   | 1.3  | -0.7 | 94.1                        | 35.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 1.3  | -0.9 | 94.1                        | 35.3     |
| -0.6                   | 1.3  | -1.1 | 94                          | 35.3     |
| -0.6                   | 1.2  | -1   | 93.9                        | 35.4     |
| -0.5                   | 1.1  | -0.9 | 93.8                        | 35.4     |
| -0.5                   | 1    | -0.6 | 93.8                        | 35.4     |
| -0.4                   | 0.9  | -0.3 | 93.8                        | 35.5     |
| -0.4                   | 0.9  | 0    | 93.8                        | 35.5     |
| -0.3                   | 0.9  | 0.4  | 93.8                        | 35.6     |
| -0.2                   | 0.9  | 0.6  | 93.9                        | 35.6     |
| -0.1                   | 1    | 0.7  | 93.9                        | 35.6     |
| 0                      | 1.1  | 0.7  | 94                          | 35.7     |
| 0                      | 1.2  | 0.6  | 94.1                        | 35.7     |
| 0.1                    | 1.2  | 0.4  | 94.1                        | 35.8     |
| 0.1                    | 1.2  | 0.2  | 94.1                        | 35.8     |
| 0                      | 1.2  | 0    | 94.1                        | 35.8     |
| 0                      | 1.2  | -0.2 | 94.1                        | 35.9     |
| 0                      | 1    | -0.4 | 94.1                        | 35.9     |
| 0                      | 0.9  | -0.4 | 94                          | 36.0     |
| 0.1                    | 0.7  | -0.4 | 94                          | 36.0     |
| 0.1                    | 0.5  | -0.3 | 94                          | 36.0     |
| 0.2                    | 0.4  | -0.2 | 94                          | 36.1     |
| 0.3                    | 0.2  | -0.1 | 94                          | 36.1     |
| 0.4                    | 0.1  | -0.1 | 94                          | 36.2     |
| 0.4                    | 0    | 0    | 94                          | 36.2     |
| 0.4                    | -0.1 | 0    | 94                          | 36.2     |
| 0.3                    | -0.1 | -0.1 | 94                          | 36.3     |
| 0.1                    | -0.1 | -0.2 | 94                          | 36.3     |
| -0.1                   | 0    | -0.3 | 94                          | 36.4     |
| -0.4                   | 0    | -0.4 | 94                          | 36.4     |
| -0.6                   | 0.1  | -0.5 | 94                          | 36.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.9                   | 0.3  | -0.6 | 94                          | 36.5     |
| -1                     | 0.4  | -0.6 | 93.9                        | 36.5     |
| -1.1                   | 0.4  | -0.4 | 93.8                        | 36.6     |
| -1.1                   | 0.5  | -0.3 | 93.5                        | 36.6     |
| -1                     | 0.5  | 0    | 93.8                        | 36.6     |
| -0.8                   | 0.4  | 0.3  | 93.8                        | 36.7     |
| -0.5                   | 0.3  | 0.6  | 93.8                        | 36.7     |
| -0.2                   | 0.2  | 0.1  | 93.9                        | 36.8     |
| 0                      | 0    | 1    | 94                          | 36.8     |
| 0.2                    | -0.2 | 1.1  | 94                          | 36.8     |
| 0.3                    | -0.3 | 1    | 94.1                        | 36.9     |
| 0.2                    | -0.4 | 0.8  | 94.2                        | 36.9     |
| 0.1                    | -0.5 | 0.5  | 94.2                        | 37.0     |
| 0                      | -0.5 | 0.2  | 94.3                        | 37.0     |
| -0.2                   | -0.4 | -0.2 | 94.3                        | 37.0     |
| -0.4                   | -0.3 | -0.5 | 94.3                        | 37.1     |
| -0.6                   | -0.1 | -0.9 | 94.2                        | 37.1     |
| -0.7                   | 0    | -1   | 94.1                        | 37.2     |
| -0.7                   | 0.2  | -1.1 | 94                          | 37.2     |
| -0.7                   | 0.3  | -1   | 94                          | 37.2     |
| -0.6                   | 0.3  | -0.9 | 93.9                        | 37.3     |
| -0.5                   | 0.3  | -0.6 | 93.9                        | 37.3     |
| -0.4                   | 0.3  | -0.2 | 93.8                        | 37.4     |
| -0.3                   | 0.2  | 0.1  | 93.8                        | 37.4     |
| -0.3                   | 0.2  | 0.3  | 93.9                        | 37.4     |
| -0.2                   | 0.1  | 0.5  | 93.9                        | 37.5     |
| -0.2                   | 0    | 0.6  | 94                          | 37.5     |
| -0.2                   | 0    | 0.5  | 94.1                        | 37.6     |
| -0.3                   | 0    | 0.3  | 94.1                        | 37.6     |
| -0.5                   | 0.1  | 0    | 94.2                        | 37.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.6                   | 0.1  | -0.3 | 94.2                        | 37.7     |
| -0.7                   | 0.3  | -0.6 | 94.1                        | 37.7     |
| -0.6                   | 0.4  | -0.9 | 94                          | 37.8     |
| -0.9                   | 0.4  | -1   | 94                          | 37.8     |
| -0.8                   | 0.4  | -1   | 93.9                        | 37.8     |
| -0.8                   | 0.4  | -0.9 | 93.8                        | 37.9     |
| -0.7                   | 0.3  | -0.7 | 93.8                        | 37.9     |
| -0.6                   | 0.1  | -0.4 | 93.7                        | 38.0     |
| -0.6                   | -0.1 | -0.1 | 93.7                        | 38.0     |
| -0.6                   | -0.2 | 0.2  | 93.7                        | 38.0     |
| -0.6                   | -0.4 | 0.5  | 93.8                        | 38.1     |
| -0.6                   | -0.4 | 0.6  | 93.9                        | 38.1     |
| -0.7                   | -0.4 | 0.6  | 93.9                        | 38.2     |
| -0.8                   | -0.3 | 0.5  | 93.9                        | 38.2     |
| -0.9                   | -0.2 | 0.3  | 94                          | 38.2     |
| -1                     | 0.1  | 0.1  | 94                          | 38.3     |
| -1.1                   | 0.3  | -0.1 | 94                          | 38.3     |
| -1                     | 0.6  | -0.3 | 94                          | 38.4     |
| -1                     | 0.8  | -0.4 | 93.9                        | 38.4     |
| -0.8                   | 0.9  | -0.4 | 93.9                        | 38.4     |
| -0.7                   | 1    | -0.3 | 93.9                        | 38.5     |
| -0.5                   | 1    | -0.2 | 93.9                        | 38.5     |
| -0.3                   | 0.9  | -0.1 | 93.9                        | 38.6     |
| -0.2                   | 0.8  | 0.1  | 93.9                        | 38.6     |
| -0.1                   | 0.7  | 0.2  | 93.9                        | 38.6     |
| 0                      | 0.6  | 0.3  | 93.9                        | 38.7     |
| 0                      | 0.5  | 0.3  | 94                          | 38.7     |
| -0.1                   | 0.4  | 0.2  | 94                          | 38.8     |
| -0.2                   | 0.3  | 0.1  | 94                          | 38.8     |
| -0.4                   | 0.3  | -0.1 | 94.1                        | 38.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.6                   | 0.3 | -0.2 | 94.1                        | 38.9     |
| -0.7                   | 0.3 | -0.4 | 94.1                        | 38.9     |
| -0.9                   | 0.3 | -0.5 | 94                          | 39.0     |
| -0.9                   | 0.4 | -0.6 | 94                          | 39.0     |
| -0.9                   | 0.4 | -0.5 | 93.9                        | 39.0     |
| -0.8                   | 0.4 | -0.4 | 93.9                        | 39.1     |
| -0.7                   | 0.4 | -0.2 | 93.8                        | 39.1     |
| -0.4                   | 0.4 | 0    | 93.8                        | 39.2     |
| -0.2                   | 0.4 | 0.3  | 93.9                        | 39.2     |
| 0.2                    | 0.4 | 0.5  | 93.9                        | 39.2     |
| 0.5                    | 0.4 | 0.7  | 94                          | 39.3     |
| 0.7                    | 0.4 | 0.7  | 94                          | 39.3     |
| 0.8                    | 0.4 | 0.7  | 94.1                        | 39.4     |
| 0.8                    | 0.5 | 0.5  | 94.1                        | 39.4     |
| 0.7                    | 0.5 | 0.2  | 94.2                        | 39.4     |
| 0.5                    | 0.5 | -0.2 | 94.2                        | 39.5     |
| 0.2                    | 0.5 | -0.5 | 94.2                        | 39.5     |
| -0.1                   | 0.4 | -0.9 | 94.2                        | 39.6     |
| -0.3                   | 0.4 | -1.2 | 94.1                        | 39.6     |
| -0.6                   | 0.3 | -1.5 | 94                          | 39.6     |
| -0.7                   | 0.3 | -1.5 | 93.9                        | 39.7     |
| -0.7                   | 0.2 | -1.4 | 93.8                        | 39.7     |
| -0.6                   | 0.2 | -1.2 | 93.7                        | 39.8     |
| -0.5                   | 0.1 | -0.8 | 93.6                        | 39.8     |
| -0.2                   | 0.1 | -0.3 | 93.6                        | 39.8     |
| 0.1                    | 0.1 | 0.2  | 93.6                        | 39.9     |
| 0.4                    | 0.1 | 0.6  | 93.6                        | 39.9     |
| 0.6                    | 0.1 | 1    | 93.7                        | 40.0     |
| 0.8                    | 0.1 | 1.3  | 93.8                        | 40.0     |
| 0.8                    | 0.1 | 1.4  | 93.9                        | 40.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.7                    | 0.1 | 1.3  | 94                          | 40.1     |
| 0.6                    | 0.2 | 1.1  | 94.1                        | 40.1     |
| 0.3                    | 0.2 | 0.7  | 94.2                        | 40.2     |
| 0                      | 0.3 | 0.4  | 94.2                        | 40.2     |
| -0.3                   | 0.3 | -0.1 | 94.2                        | 40.2     |
| -0.6                   | 0.4 | -0.5 | 94.2                        | 40.3     |
| -0.8                   | 0.4 | -0.8 | 94.1                        | 40.3     |
| -0.9                   | 0.4 | -1   | 94.1                        | 40.4     |
| -0.9                   | 0.5 | -1   | 94                          | 40.4     |
| -0.8                   | 0.5 | -0.9 | 93.9                        | 40.4     |
| -0.6                   | 0.4 | -0.6 | 93.8                        | 40.5     |
| -0.4                   | 0.4 | -0.3 | 93.8                        | 40.5     |
| -0.2                   | 0.3 | 0.1  | 93.8                        | 40.6     |
| 0                      | 0.2 | 0.5  | 93.8                        | 40.6     |
| 0.2                    | 0.2 | 0.7  | 93.9                        | 40.6     |
| 0.3                    | 0.1 | 0.9  | 94                          | 40.7     |
| 0.3                    | 0   | 0.9  | 94.1                        | 40.7     |
| 0.3                    | 0   | 0.8  | 94.2                        | 40.8     |
| 0.1                    | 0   | 0.7  | 94.2                        | 40.8     |
| -0.1                   | 0   | 0.4  | 94.2                        | 40.8     |
| -0.3                   | 0.1 | 0    | 94.2                        | 40.9     |
| -0.6                   | 0.1 | -0.3 | 94.2                        | 40.9     |
| -0.8                   | 0.2 | -0.5 | 94.2                        | 41.0     |
| -0.9                   | 0.3 | -0.7 | 94.2                        | 41.0     |
| -1                     | 0.4 | -0.8 | 94.1                        | 41.0     |
| -0.9                   | 0.5 | -0.9 | 94.1                        | 41.1     |
| -0.8                   | 0.5 | -0.9 | 94                          | 41.1     |
| -0.6                   | 0.6 | -0.8 | 93.9                        | 41.2     |
| -0.4                   | 0.6 | -0.6 | 93.9                        | 41.2     |
| -0.2                   | 0.6 | -0.4 | 93.9                        | 41.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0                      | 0.6  | -0.2 | 93.9                        | 41.3     |
| 0.1                    | 0.6  | -0.1 | 93.9                        | 41.3     |
| 0.1                    | 0.6  | -0.1 | 93.9                        | 41.4     |
| 0                      | 0.6  | 0    | 93.9                        | 41.4     |
| -0.1                   | 0.6  | 0    | 93.9                        | 41.4     |
| -0.3                   | 0.6  | -0.1 | 93.9                        | 41.5     |
| -0.4                   | 0.6  | -0.1 | 93.9                        | 41.5     |
| -0.6                   | 0.6  | -0.2 | 93.9                        | 41.6     |
| -0.3                   | 0.5  | -0.2 | 93.9                        | 41.6     |
| -1                     | 0.5  | -0.1 | 93.9                        | 41.6     |
| -1.1                   | 0.5  | 0    | 93.9                        | 41.7     |
| -1.2                   | 0.5  | 0.1  | 93.9                        | 41.7     |
| -1.2                   | 0.5  | 0.3  | 93.9                        | 41.8     |
| -1.1                   | 0.4  | 0.4  | 93.9                        | 41.8     |
| -1.1                   | 0.4  | 0.5  | 93.9                        | 41.8     |
| -0.9                   | 0.4  | 0.6  | 94                          | 41.9     |
| -0.8                   | 0.4  | 0.6  | 94                          | 41.9     |
| -0.6                   | 0.3  | 0.5  | 94.1                        | 42.0     |
| -0.5                   | 0.3  | 0.3  | 94.2                        | 42.0     |
| -0.4                   | 0.3  | 0    | 94.2                        | 42.0     |
| -0.3                   | 0.2  | -0.2 | 94.2                        | 42.1     |
| -0.3                   | 0.2  | -0.5 | 94.1                        | 42.1     |
| -0.3                   | 0.1  | -0.6 | 94.1                        | 42.2     |
| -0.4                   | 0    | -0.7 | 94                          | 42.2     |
| -0.5                   | -0.1 | -0.7 | 94                          | 42.2     |
| -0.6                   | -0.3 | -0.7 | 93.9                        | 42.3     |
| -0.7                   | -0.4 | -0.5 | 93.9                        | 42.3     |
| -0.7                   | -0.5 | -0.4 | 93.9                        | 42.4     |
| -0.7                   | -0.6 | -0.2 | 93.9                        | 42.4     |
| -0.7                   | -0.7 | 0    | 93.9                        | 42.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.7                   | -0.7 | 0.1  | 93.9                        | 42.5     |
| -0.6                   | -0.8 | 0.2  | 93.9                        | 42.5     |
| -0.5                   | -0.7 | 0.2  | 94                          | 42.6     |
| -0.5                   | -0.7 | 0.2  | 94                          | 42.6     |
| -0.4                   | -0.6 | 0.1  | 94                          | 42.6     |
| -0.4                   | -0.5 | -0.1 | 94                          | 42.7     |
| -0.4                   | -0.4 | -0.2 | 94                          | 42.7     |
| -0.4                   | -0.3 | -0.3 | 94                          | 42.8     |
| -0.5                   | -0.1 | -0.4 | 94                          | 42.8     |
| -0.5                   | 0    | -0.5 | 93.9                        | 42.8     |
| -0.5                   | 0.1  | -0.5 | 93.9                        | 42.9     |
| -0.5                   | 0.2  | -0.4 | 93.9                        | 42.9     |
| -0.5                   | 0.3  | -0.3 | 93.8                        | 43.0     |
| -0.4                   | 0.3  | -0.1 | 93.8                        | 43.0     |
| -0.3                   | 0.4  | 0.1  | 93.8                        | 43.0     |
| -0.2                   | 0.4  | 0.2  | 93.8                        | 43.1     |
| -0.2                   | 0.5  | 0.4  | 93.9                        | 43.1     |
| -0.1                   | 0.5  | 0.4  | 93.9                        | 43.2     |
| -0.1                   | 0.5  | 0.4  | 94                          | 43.2     |
| -0.1                   | 0.5  | 0.3  | 94                          | 43.2     |
| -0.2                   | 0.5  | 0.2  | 94                          | 43.3     |
| -0.3                   | 0.4  | 0    | 94.1                        | 43.3     |
| -0.3                   | 0.4  | -0.2 | 94                          | 43.4     |
| -0.4                   | 0.4  | -0.3 | 94                          | 43.4     |
| -0.3                   | 0.4  | -0.5 | 94                          | 43.4     |
| -0.3                   | 0.4  | -0.6 | 94                          | 43.5     |
| -0.1                   | 0.4  | -0.5 | 93.9                        | 43.5     |
| 0                      | 0.4  | -0.5 | 93.9                        | 43.6     |
| 0.2                    | 0.4  | -0.5 | 93.9                        | 43.6     |
| 0.4                    | 0.3  | -0.3 | 93.8                        | 43.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.6                    | 0.3 | -0.1 | 93.8                        | 43.7     |
| 0.8                    | 0.3 | 0.1  | 93.8                        | 43.7     |
| 0.8                    | 0.2 | 0.2  | 93.9                        | 43.8     |
| 0.8                    | 0.2 | 0.3  | 93.9                        | 43.8     |
| 0.8                    | 0.2 | 0.4  | 93.9                        | 43.8     |
| 0.6                    | 0.2 | 0.3  | 94                          | 43.9     |
| 0.4                    | 0.2 | 0.3  | 94                          | 43.9     |
| 0.2                    | 0.2 | 0.2  | 94                          | 44.0     |
| -0.1                   | 0.3 | 0    | 94                          | 44.0     |
| -0.3                   | 0.3 | -0.1 | 94                          | 44.0     |
| -0.6                   | 0.4 | -0.3 | 94                          | 44.1     |
| -0.8                   | 0.6 | -0.4 | 94                          | 44.1     |
| -0.9                   | 0.7 | -0.5 | 94                          | 44.2     |
| -1                     | 0.8 | -0.5 | 93.9                        | 44.2     |
| -1                     | 0.9 | -0.5 | 93.9                        | 44.2     |
| -0.9                   | 1   | -0.3 | 93.9                        | 44.3     |
| -0.8                   | 1   | -0.2 | 93.9                        | 44.3     |
| -0.6                   | 1   | 0    | 93.9                        | 44.4     |
| -0.4                   | 1   | 0.2  | 93.9                        | 44.4     |
| -0.3                   | 1   | 0.4  | 93.9                        | 44.4     |
| -0.1                   | 0.9 | 0.5  | 93.9                        | 44.5     |
| -0.1                   | 0.8 | 0.6  | 94                          | 44.5     |
| 0                      | 0.8 | 0.6  | 94                          | 44.6     |
| -0.1                   | 0.7 | 0.6  | 94.1                        | 44.6     |
| -0.1                   | 0.7 | 0.5  | 94.1                        | 44.6     |
| -0.2                   | 0.6 | 0.3  | 94.1                        | 44.7     |
| -0.3                   | 0.6 | 0.1  | 94.2                        | 44.7     |
| -0.4                   | 0.6 | -0.1 | 94.2                        | 44.8     |
| -0.4                   | 0.5 | -0.3 | 94.1                        | 44.8     |
| -0.4                   | 0.5 | -0.4 | 94.1                        | 44.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.3                   | 0.5  | -0.5 | 94.1                        | 44.9     |
| -0.2                   | 0.4  | -0.5 | 94                          | 44.9     |
| 0                      | 0.4  | -0.4 | 94                          | 45.0     |
| 0                      | 0.4  | -0.4 | 94                          | 45.0     |
| 0.2                    | 0.4  | -0.2 | 94                          | 45.0     |
| 0.2                    | 0.3  | -0.1 | 94                          | 45.1     |
| 0.2                    | 0.3  | 0    | 94                          | 45.1     |
| 0.2                    | 0.2  | 0    | 94                          | 45.2     |
| 0.1                    | 0.2  | 0.1  | 94                          | 45.2     |
| -0.1                   | 0.1  | 0    | 94                          | 45.2     |
| -0.3                   | 0.1  | 0    | 94                          | 45.3     |
| -0.4                   | 0.1  | -0.1 | 94.1                        | 45.3     |
| -0.6                   | 0.1  | -0.2 | 94                          | 45.4     |
| -0.7                   | 0.1  | -0.3 | 94                          | 45.4     |
| -0.7                   | 0.1  | -0.3 | 94                          | 45.4     |
| -0.7                   | 0.1  | -0.4 | 94                          | 45.5     |
| -0.6                   | 0.1  | -0.3 | 93.9                        | 45.5     |
| -0.5                   | 0.1  | -0.2 | 93.9                        | 45.6     |
| -0.4                   | 0    | -0.1 | 93.9                        | 45.6     |
| -0.2                   | -0.1 | 0    | 93.9                        | 45.6     |
| -0.2                   | -0.1 | 0.1  | 93.9                        | 45.7     |
| -0.1                   | -0.3 | 0.2  | 93.9                        | 45.7     |
| -0.2                   | -0.4 | 0.3  | 94                          | 45.8     |
| -0.3                   | -0.5 | 0.3  | 93.9                        | 45.8     |
| -0.5                   | -0.6 | 0.2  | 94                          | 45.8     |
| -0.7                   | -0.6 | 0.2  | 94                          | 45.9     |
| -0.9                   | -0.7 | 0    | 94.1                        | 45.9     |
| -1.2                   | -0.7 | -0.2 | 94.1                        | 46.0     |
| -1.3                   | -0.7 | -0.3 | 94.1                        | 46.0     |
| -1.4                   | -0.6 | -0.4 | 94                          | 46.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -1.4                   | -0.5 | -0.5 | 94                          | 46.1     |
| -1.3                   | -0.4 | -0.5 | 93.9                        | 46.1     |
| -1.1                   | -0.2 | -0.5 | 93.9                        | 46.2     |
| -0.8                   | -0.1 | -0.4 | 93.9                        | 46.2     |
| -0.5                   | 0.1  | -0.3 | 93.9                        | 46.2     |
| -0.2                   | 0.2  | -0.1 | 93.9                        | 46.3     |
| 0                      | 0.2  | 0    | 93.9                        | 46.3     |
| 0.1                    | 0.3  | 0.1  | 93.9                        | 46.4     |
| 0.2                    | 0.2  | 0.2  | 93.9                        | 46.4     |
| 0.2                    | 0.2  | 0.2  | 93.9                        | 46.4     |
| 0                      | 0.1  | 0.1  | 94                          | 46.5     |
| -0.2                   | 0    | 0.1  | 94                          | 46.5     |
| -0.4                   | -0.2 | -0.1 | 94                          | 46.6     |
| -0.6                   | -0.3 | -0.2 | 94                          | 46.6     |
| -0.9                   | -0.4 | -0.3 | 94                          | 46.6     |
| -1                     | -0.5 | -0.4 | 94                          | 46.7     |
| -1.2                   | -0.5 | -0.5 | 93.9                        | 46.7     |
| -1.2                   | -0.5 | -0.5 | 93.9                        | 46.8     |
| -1.1                   | -0.5 | -0.4 | 93.8                        | 46.8     |
| -1                     | -0.4 | -0.2 | 94                          | 46.8     |
| -0.8                   | -0.2 | 0    | 93.4                        | 46.9     |
| -0.5                   | -0.1 | 0.3  | 93.8                        | 46.9     |
| -0.2                   | 0.1  | 0.5  | 93.9                        | 47.0     |
| 0                      | 0.3  | 0.7  | 93.9                        | 47.0     |
| 0.2                    | 0.5  | 0.7  | 94                          | 47.0     |
| 0.4                    | 0.7  | 0.7  | 94                          | 47.1     |
| 0.5                    | 0.8  | 0.6  | 94.1                        | 47.1     |
| 0.5                    | 1    | 0.4  | 94.2                        | 47.2     |
| 0.4                    | 1    | 0.1  | 94.2                        | 47.2     |
| 0.3                    | 1.1  | -0.3 | 94.2                        | 47.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.1                    | 1.1  | -0.6 | 94.2                        | 47.3     |
| -0.1                   | 1.1  | -1   | 94.1                        | 47.3     |
| -0.3                   | 1.1  | -1.2 | 94                          | 47.4     |
| -0.5                   | 1    | -1.2 | 93.9                        | 47.4     |
| -0.6                   | 1    | -1.2 | 93.8                        | 47.4     |
| -0.7                   | 0.9  | -1   | 93.8                        | 47.5     |
| -0.7                   | 0.2  | -0.7 | 93.7                        | 47.5     |
| -0.6                   | 0.8  | -0.4 | 93.7                        | 47.6     |
| -0.5                   | 0.7  | 0    | 93.7                        | 47.6     |
| -0.3                   | 0.7  | 0.3  | 93.7                        | 47.6     |
| -0.1                   | 0.6  | 0.6  | 93.8                        | 47.7     |
| 0.1                    | 0.6  | 0.7  | 93.8                        | 47.7     |
| 0.2                    | 0.6  | 0.7  | 93.9                        | 47.8     |
| 0.3                    | 0.6  | 0.7  | 94                          | 47.8     |
| 0.3                    | 0.6  | 0.6  | 94                          | 47.8     |
| 0.3                    | 0.6  | 0.4  | 94                          | 47.9     |
| 0.2                    | 0.6  | 0.2  | 94.1                        | 47.9     |
| 0.1                    | 0.7  | 0    | 94                          | 48.0     |
| 0                      | 0.8  | -0.2 | 94                          | 48.0     |
| -0.2                   | 0.8  | -0.3 | 94                          | 48.0     |
| -0.3                   | 0.8  | -0.3 | 94                          | 48.1     |
| -0.4                   | 0.8  | -0.3 | 94                          | 48.1     |
| -0.5                   | 0.7  | -0.3 | 93.9                        | 48.2     |
| -0.5                   | 0.5  | -0.2 | 93.9                        | 48.2     |
| -0.5                   | 0.4  | -0.1 | 93.9                        | 48.2     |
| -0.5                   | 0.2  | 0.1  | 93.9                        | 48.3     |
| -0.4                   | 0    | 0.2  | 94                          | 48.3     |
| -0.3                   | -0.2 | 0.3  | 94                          | 48.4     |
| -0.2                   | -0.4 | 0.3  | 94                          | 48.4     |
| 0                      | -0.5 | 0.2  | 94                          | 48.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.1                    | -0.5 | 0.2  | 94                          | 48.5     |
| 0.1                    | -0.4 | 0.1  | 94.1                        | 48.5     |
| 0.2                    | -0.3 | 0.1  | 94.1                        | 48.6     |
| 0.3                    | -0.1 | 0    | 94.1                        | 48.6     |
| 0.3                    | 0.1  | -0.1 | 94.1                        | 48.6     |
| 0.4                    | 0.2  | -0.1 | 94.1                        | 48.7     |
| 0.4                    | 0.4  | -0.2 | 94                          | 48.7     |
| 0.4                    | 0.5  | -0.1 | 94                          | 48.8     |
| 0.4                    | 0.6  | 0    | 94                          | 48.8     |
| 0.3                    | 0.6  | 0.1  | 94                          | 48.8     |
| 0.2                    | 0.5  | 0.1  | 94                          | 48.9     |
| 0.1                    | 0.5  | 0.1  | 94.1                        | 48.9     |
| 0                      | 0.3  | 0    | 94.1                        | 49.0     |
| -0.2                   | 0.2  | 0    | 94.1                        | 49.0     |
| -0.3                   | 0.1  | -0.1 | 94.1                        | 49.0     |
| -0.5                   | 0    | -0.3 | 94.1                        | 49.1     |
| -0.6                   | 0    | -0.6 | 94.1                        | 49.1     |
| -0.7                   | -0.1 | -0.7 | 94.1                        | 49.2     |
| -0.7                   | -0.1 | -0.8 | 94                          | 49.2     |
| -0.7                   | 0    | -0.7 | 94                          | 49.2     |
| -0.7                   | 0    | -0.7 | 93.9                        | 49.3     |
| -0.6                   | 0.1  | -0.7 | 93.9                        | 49.3     |
| -0.5                   | 0.1  | -0.3 | 93.8                        | 49.4     |
| -0.4                   | 0.2  | -0.1 | 93.8                        | 49.4     |
| -0.3                   | 0.2  | 0.1  | 93.8                        | 49.4     |
| -0.2                   | 0.2  | 0.4  | 93.1                        | 49.5     |
| -0.2                   | 0.1  | 0.7  | 93.9                        | 49.5     |
| -0.1                   | 0.1  | 0.8  | 93.9                        | 49.6     |
| -0.2                   | 0    | 0.8  | 94                          | 49.6     |
| -0.3                   | -0.1 | 0.6  | 94.1                        | 49.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.4                   | -0.1 | 0.5  | 94.1                        | 49.7     |
| -0.5                   | -0.2 | 0.2  | 94.2                        | 49.7     |
| -0.6                   | -0.2 | -0.1 | 94.2                        | 49.8     |
| -0.7                   | -0.2 | -0.4 | 94.1                        | 49.8     |
| -0.3                   | -0.2 | -0.7 | 94.1                        | 49.8     |
| -0.8                   | -0.2 | -0.8 | 94                          | 49.9     |
| -0.8                   | -0.1 | -0.8 | 93.9                        | 49.9     |
| -0.7                   | -0.1 | -0.9 | 93.9                        | 50.0     |
| -0.6                   | -0.1 | -0.7 | 93.8                        | 50.0     |
| -0.4                   | -0.1 | -0.5 | 93                          | 50.0     |
| -0.3                   | -0.1 | -0.2 | 93.8                        | 50.1     |
| -0.2                   | -0.1 | 0.1  | 93.8                        | 50.1     |
| -0.1                   | -0.1 | 0.3  | 93.8                        | 50.2     |
| -0.1                   | 0    | 0.4  | 93.9                        | 50.2     |
| -0.2                   | 0.1  | 0.4  | 93.9                        | 50.2     |
| -0.3                   | 0.2  | 0.5  | 94                          | 50.3     |
| -0.5                   | 0.3  | 0.5  | 94                          | 50.3     |
| -0.7                   | 0.5  | 0.3  | 94                          | 50.4     |
| -0.9                   | 0.6  | 0.1  | 94.1                        | 50.4     |
| -1.1                   | 0.7  | 0    | 94.1                        | 50.4     |
| -1.3                   | 0.7  | -0.1 | 94.1                        | 50.5     |
| -1.3                   | 0.7  | -0.2 | 94                          | 50.5     |
| -1.3                   | 0.7  | -0.3 | 94                          | 50.6     |
| -1.2                   | 0.6  | -0.4 | 94                          | 50.6     |
| -1                     | 0.5  | -0.3 | 93.9                        | 50.6     |
| -0.7                   | 0.4  | -0.2 | 93.9                        | 50.7     |
| -0.5                   | 0.3  | -0.1 | 93.9                        | 50.7     |
| -0.3                   | 0.3  | 0.1  | 93.9                        | 50.8     |
| -0.1                   | 0.2  | 0.2  | 94                          | 50.8     |
| 0                      | 0.2  | 0.2  | 94                          | 50.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0                      | 0.2  | 0.3  | 94                          | 50.9     |
| -0.1                   | 0.2  | 0.2  | 94                          | 50.9     |
| -0.2                   | 0.3  | 0.1  | 94.1                        | 51.0     |
| -0.4                   | 0.3  | 0    | 94.1                        | 51.0     |
| -0.5                   | 0.4  | -0.2 | 94.1                        | 51.0     |
| -0.7                   | 0.4  | -0.5 | 94.1                        | 51.1     |
| -0.8                   | 0.5  | -0.6 | 94                          | 51.1     |
| -0.8                   | 0.5  | -0.7 | 94                          | 51.2     |
| -0.7                   | 0.5  | -0.8 | 93.9                        | 51.2     |
| -0.5                   | 0.5  | -0.7 | 93.9                        | 51.2     |
| -0.3                   | 0.5  | -0.6 | 93.8                        | 51.3     |
| 0                      | 0.4  | -0.5 | 93.8                        | 51.3     |
| 0.3                    | 0.4  | -0.3 | 93.8                        | 51.4     |
| 0.5                    | 0.3  | -0.1 | 93.8                        | 51.4     |
| 0.7                    | 0.1  | 0    | 93.8                        | 51.4     |
| 0.9                    | 0    | 0.2  | 93.8                        | 51.5     |
| 0.9                    | -0.2 | 0.3  | 93.9                        | 51.5     |
| 0.8                    | -0.3 | 0.3  | 93.9                        | 51.6     |
| 0.7                    | -0.4 | 0.2  | 93.9                        | 51.6     |
| 0.5                    | -0.4 | 0.2  | 93.9                        | 51.6     |
| 0.2                    | -0.4 | 0.1  | 93.9                        | 51.7     |
| -0.2                   | -0.3 | 0    | 94                          | 51.7     |
| -0.4                   | -0.2 | -0.1 | 93.9                        | 51.8     |
| -0.6                   | 0    | -0.2 | 93.9                        | 51.8     |
| -0.7                   | 0.1  | -0.2 | 93.9                        | 51.8     |
| -0.8                   | 0.3  | -0.2 | 93.9                        | 51.9     |
| -0.7                   | 0.5  | -0.1 | 93.9                        | 51.9     |
| -0.6                   | 0.6  | 0.1  | 93.9                        | 52.0     |
| -0.4                   | 0.7  | 0.2  | 93.9                        | 52.0     |
| -0.2                   | 0.7  | 0.4  | 93.9                        | 52.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0                      | 0.7 | 0.6  | 93.9                        | 52.1     |
| 0.2                    | 0.6 | 0.7  | 93.9                        | 52.1     |
| 0.3                    | 0.5 | 0.7  | 94                          | 52.2     |
| 0.3                    | 0.4 | 0.6  | 94.1                        | 52.2     |
| 0.3                    | 0.3 | 0.5  | 94.1                        | 52.2     |
| 0.3                    | 0.2 | 0.3  | 94.2                        | 52.3     |
| 0.1                    | 0.1 | 0    | 94.2                        | 52.3     |
| -0.1                   | 0   | -0.3 | 94.2                        | 52.4     |
| -0.2                   | 0   | -0.5 | 94.2                        | 52.4     |
| -0.4                   | 0   | -0.8 | 94.1                        | 52.4     |
| -0.4                   | 0   | -0.9 | 94.1                        | 52.5     |
| -0.5                   | 0   | -0.9 | 94                          | 52.5     |
| -0.4                   | 0.1 | -0.9 | 93.9                        | 52.6     |
| -0.3                   | 0.1 | -0.7 | 93.9                        | 52.6     |
| -0.1                   | 0.2 | -0.4 | 94                          | 52.6     |
| 0.1                    | 0.2 | -0.1 | 93.8                        | 52.7     |
| 0.3                    | 0.2 | 0.2  | 93.8                        | 52.7     |
| 0.4                    | 0.2 | 0.4  | 93.9                        | 52.8     |
| 0.5                    | 0.2 | 0.6  | 93.9                        | 52.8     |
| 0.5                    | 0.2 | 0.6  | 94                          | 52.8     |
| 0.5                    | 0.3 | 0.5  | 94.1                        | 52.9     |
| 0.4                    | 0.3 | 0.4  | 94.1                        | 52.9     |
| 0.2                    | 0.4 | 0.1  | 94.1                        | 53.0     |
| 0.1                    | 0.5 | -0.2 | 94.1                        | 53.0     |
| -0.1                   | 0.7 | -0.4 | 94.1                        | 53.0     |
| -0.2                   | 0.8 | -0.6 | 94.1                        | 53.1     |
| -0.3                   | 0.9 | -0.7 | 94                          | 53.1     |
| -0.4                   | 1   | -0.7 | 93.9                        | 53.2     |
| -0.4                   | 1   | -0.6 | 93.9                        | 53.2     |
| -0.4                   | 1   | -0.5 | 93.8                        | 53.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.4                   | 1    | -0.2 | 93.8                        | 53.3     |
| -0.4                   | 0.9  | 0    | 93.8                        | 53.3     |
| -0.3                   | 0.8  | 0.3  | 93.8                        | 53.4     |
| -0.3                   | 0.7  | 0.5  | 93.9                        | 53.4     |
| -0.3                   | 0.6  | 0.6  | 93.9                        | 53.4     |
| -0.3                   | 0.5  | 0.7  | 94                          | 53.5     |
| -0.4                   | 0.5  | 0.7  | 94                          | 53.5     |
| -0.4                   | 0.4  | 0.5  | 94.1                        | 53.6     |
| -0.5                   | 0.4  | 0.4  | 94.1                        | 53.6     |
| -0.6                   | 0.5  | 0.2  | 94.1                        | 53.6     |
| -0.7                   | 0.5  | 0    | 94.1                        | 53.7     |
| -0.7                   | 0.5  | -0.1 | 94.1                        | 53.7     |
| -0.7                   | 0.4  | -0.2 | 94.1                        | 53.8     |
| -0.7                   | 0.3  | -0.3 | 94.1                        | 53.8     |
| -0.6                   | 0.2  | -0.4 | 94.1                        | 53.8     |
| -0.6                   | 0.1  | -0.4 | 94                          | 53.9     |
| -0.5                   | 0    | -0.3 | 94                          | 53.9     |
| -0.4                   | -0.1 | -0.3 | 94                          | 54.0     |
| -0.4                   | -0.2 | -0.3 | 94                          | 54.0     |
| -0.4                   | -0.3 | -0.2 | 94                          | 54.0     |
| -0.4                   | -0.3 | -0.2 | 94                          | 54.1     |
| -0.5                   | -0.3 | -0.2 | 94                          | 54.1     |
| -0.6                   | -0.3 | -0.2 | 94                          | 54.2     |
| -0.7                   | -0.2 | -0.2 | 94                          | 54.2     |
| -0.7                   | -0.2 | -0.2 | 94                          | 54.2     |
| -0.8                   | -0.1 | -0.3 | 94                          | 54.3     |
| -0.8                   | 0    | -0.3 | 93.9                        | 54.3     |
| -0.8                   | 0.1  | -0.2 | 93.9                        | 54.4     |
| -0.7                   | 0.1  | -0.2 | 93.9                        | 54.4     |
| -0.7                   | 0.1  | -0.1 | 93.9                        | 54.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.6                   | 0.1  | 0    | 93.9                        | 54.5     |
| -0.5                   | 0    | 0.1  | 93.9                        | 54.5     |
| -0.4                   | -0.1 | 0.2  | 93.9                        | 54.6     |
| -0.3                   | -0.2 | 0.3  | 93.9                        | 54.6     |
| -0.2                   | -0.3 | 0.3  | 93.9                        | 54.6     |
| -0.2                   | -0.4 | 0.3  | 94                          | 54.7     |
| -0.2                   | -0.5 | 0.3  | 94                          | 54.7     |
| -0.3                   | -0.5 | 0.2  | 94                          | 54.8     |
| -0.3                   | -0.4 | 0    | 94.1                        | 54.8     |
| -0.3                   | -0.3 | -0.1 | 94.1                        | 54.8     |
| -0.4                   | -0.2 | -0.3 | 94.1                        | 54.9     |
| -0.4                   | 0    | -0.4 | 94                          | 54.9     |
| -0.4                   | 0.2  | -0.5 | 94                          | 55.0     |
| -0.4                   | 0.4  | -0.5 | 94                          | 55.0     |
| -0.3                   | 0.5  | -0.5 | 93.9                        | 55.0     |
| -0.2                   | 0.6  | -0.4 | 93.9                        | 55.1     |
| -0.1                   | 0.6  | -0.3 | 93.9                        | 55.1     |
| 0                      | 0.5  | -0.1 | 93.9                        | 55.2     |
| 0.1                    | 0.4  | 0    | 93.9                        | 55.2     |
| 0.2                    | 0.3  | 0.1  | 93.9                        | 55.2     |
| 0.2                    | 0.1  | 0.2  | 93.9                        | 55.3     |
| 0.2                    | -0.1 | 0.2  | 93.9                        | 55.3     |
| 0.2                    | -0.2 | 0.1  | 94                          | 55.4     |
| 0.1                    | -0.3 | 0    | 94                          | 55.4     |
| 0                      | -0.3 | -0.1 | 94                          | 55.4     |
| -0.1                   | -0.3 | -0.2 | 94                          | 55.5     |
| -0.3                   | -0.2 | -0.3 | 94                          | 55.5     |
| -0.4                   | -0.1 | -0.3 | 93.9                        | 55.6     |
| -0.5                   | 0.1  | -0.3 | 93.9                        | 55.6     |
| -0.5                   | 0.2  | -0.3 | 93.9                        | 55.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.5                   | 0.4 | -0.2 | 93.9                        | 55.7     |
| -0.4                   | 0.5 | -0.1 | 93.8                        | 55.7     |
| -0.3                   | 0.6 | 0    | 93.8                        | 55.8     |
| -0.2                   | 0.7 | 0.2  | 93.9                        | 55.8     |
| -0.1                   | 0.7 | 0.3  | 93.9                        | 55.8     |
| 0                      | 0.7 | 0.4  | 93.9                        | 55.9     |
| 0.1                    | 0.7 | 0.4  | 93.9                        | 55.9     |
| 0.2                    | 0.6 | 0.3  | 94                          | 56.0     |
| 0.2                    | 0.5 | 0.2  | 94                          | 56.0     |
| 0.1                    | 0.4 | 0    | 94.1                        | 56.0     |
| 0                      | 0.4 | -0.1 | 94.1                        | 56.1     |
| -0.1                   | 0.4 | -0.3 | 94                          | 56.1     |
| -0.2                   | 0.4 | -0.4 | 94                          | 56.2     |
| -0.3                   | 0.4 | -0.5 | 94                          | 56.2     |
| -0.3                   | 0.4 | -0.5 | 93.9                        | 56.2     |
| -0.4                   | 0.5 | -0.4 | 93.9                        | 56.3     |
| -0.3                   | 0.6 | -0.2 | 93.9                        | 56.3     |
| -0.2                   | 0.7 | -0.1 | 93.9                        | 56.4     |
| -0.1                   | 0.7 | 0.1  | 93.9                        | 56.4     |
| 0.1                    | 0.8 | 0.3  | 93.9                        | 56.4     |
| 0.3                    | 0.9 | 0.5  | 93.9                        | 56.5     |
| 0.4                    | 1   | 0.6  | 94                          | 56.5     |
| 0.5                    | 1   | 0.7  | 94                          | 56.6     |
| 0.6                    | 1.1 | 0.6  | 94.1                        | 56.6     |
| 0.6                    | 1.1 | 0.5  | 94.1                        | 56.6     |
| 0.5                    | 1.1 | 0.3  | 94.2                        | 56.7     |
| 0.4                    | 1.1 | 0.1  | 94.2                        | 56.7     |
| 0.2                    | 1.1 | -0.2 | 94.2                        | 56.8     |
| 0                      | 1   | -0.4 | 94.1                        | 56.8     |
| -0.2                   | 1   | -0.6 | 94.1                        | 56.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.3                   | 0.9  | -0.7 | 94                          | 56.9     |
| -0.4                   | 0.8  | -0.7 | 94                          | 56.9     |
| -0.5                   | 0.8  | -0.6 | 93.9                        | 57.0     |
| -0.5                   | 0.6  | -0.4 | 93.9                        | 57.0     |
| -0.4                   | 0.6  | -0.2 | 93.9                        | 57.0     |
| -0.3                   | 0.5  | 0.1  | 93.9                        | 57.1     |
| -0.2                   | 0.4  | 0.3  | 93.9                        | 57.1     |
| -0.1                   | 0.3  | 0.4  | 93.9                        | 57.2     |
| 0                      | 0.2  | 0.5  | 94                          | 57.2     |
| 0.1                    | 0.2  | 0.6  | 94                          | 57.2     |
| 0.1                    | 0.1  | 0.5  | 94.1                        | 57.3     |
| 0.1                    | 0.1  | 0.4  | 94.1                        | 57.3     |
| 0.1                    | 0.1  | 0.1  | 94.2                        | 57.4     |
| 0                      | 0.1  | -0.1 | 94.2                        | 57.4     |
| 0                      | 0.1  | -0.3 | 94.1                        | 57.4     |
| -0.1                   | 0    | -0.6 | 94.1                        | 57.5     |
| -0.2                   | 0    | -0.7 | 94.1                        | 57.5     |
| -0.3                   | -0.1 | -0.8 | 94                          | 57.6     |
| -0.3                   | -0.1 | -0.8 | 93.9                        | 57.6     |
| -0.3                   | -0.2 | -0.7 | 93.9                        | 57.6     |
| -0.3                   | -0.2 | -0.5 | 93.8                        | 57.7     |
| -0.3                   | -0.3 | -0.2 | 93.8                        | 57.7     |
| -0.3                   | -0.4 | 0    | 93.8                        | 57.8     |
| -0.3                   | -0.4 | 0.3  | 93.8                        | 57.8     |
| -0.3                   | -0.4 | 0.4  | 93.9                        | 57.8     |
| -0.4                   | -0.4 | 0.5  | 93.9                        | 57.9     |
| -0.4                   | -0.3 | 0.5  | 94                          | 57.9     |
| -0.4                   | -0.3 | 0.4  | 94                          | 58.0     |
| -0.5                   | -0.2 | 0.2  | 94.1                        | 58.0     |
| -0.6                   | 0    | 0    | 94.1                        | 58.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.6                   | 0.1  | -0.2 | 94.1                        | 58.1     |
| -0.7                   | 0.1  | -0.3 | 94                          | 58.1     |
| -0.7                   | 0.2  | -0.4 | 94                          | 58.2     |
| -0.7                   | 0.2  | -0.4 | 93.9                        | 58.2     |
| -0.7                   | 0.2  | -0.4 | 93.9                        | 58.2     |
| -0.7                   | 0.1  | -0.2 | 93.9                        | 58.3     |
| -0.6                   | 0    | 0    | 93.9                        | 58.3     |
| -0.6                   | -0.1 | 0.2  | 93.9                        | 58.4     |
| -0.5                   | -0.3 | 0.4  | 93.9                        | 58.4     |
| -0.4                   | -0.3 | 0.5  | 93.9                        | 58.4     |
| -0.3                   | -0.4 | 0.6  | 94                          | 58.5     |
| -0.2                   | -0.4 | 0.6  | 94.1                        | 58.5     |
| -0.2                   | -0.4 | 0.5  | 94.1                        | 58.6     |
| -0.2                   | -0.4 | 0.4  | 94.1                        | 58.6     |
| -0.2                   | -0.3 | 0.2  | 94.2                        | 58.6     |
| -0.2                   | -0.1 | -0.1 | 94.2                        | 58.7     |
| -0.3                   | 0    | -0.3 | 94.2                        | 58.7     |
| -0.4                   | 0.2  | -0.6 | 94.1                        | 58.8     |
| -0.4                   | 0.3  | -0.7 | 94.1                        | 58.8     |
| -0.4                   | 0.4  | -0.8 | 94                          | 58.8     |
| -0.4                   | 0.5  | -0.9 | 94                          | 58.9     |
| -0.4                   | 0.6  | -0.8 | 93.9                        | 58.9     |
| -0.4                   | 0.6  | -0.7 | 93.9                        | 59.0     |
| -0.3                   | 0.6  | -0.6 | 93.8                        | 59.0     |
| -0.2                   | 0.6  | -0.5 | 93.8                        | 59.0     |
| -0.1                   | 0.6  | -0.3 | 93.8                        | 59.1     |
| 0                      | 0.6  | -0.2 | 93.8                        | 59.1     |
| 0.1                    | 0.6  | 0    | 93.8                        | 59.2     |
| 0.1                    | 0.5  | 0.1  | 94                          | 59.2     |
| 0.1                    | 0.5  | 0.1  | 93.8                        | 59.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0                      | 0.5 | 0.1  | 93.8                        | 59.3     |
| -0.1                   | 0.5 | 0.1  | 93.9                        | 59.3     |
| -0.3                   | 0.5 | 0.1  | 93.9                        | 59.4     |
| -0.4                   | 0.5 | 0.1  | 93.9                        | 59.4     |
| -0.5                   | 0.5 | 0.1  | 93.9                        | 59.4     |
| -0.6                   | 0.5 | 0    | 93.9                        | 59.5     |
| -0.7                   | 0.5 | 0    | 93.9                        | 59.5     |
| -0.6                   | 0.5 | 0    | 93.9                        | 59.6     |
| -0.6                   | 0.6 | 0.1  | 93.9                        | 59.6     |
| -0.5                   | 0.6 | 0.1  | 93.9                        | 59.6     |
| -0.4                   | 0.7 | 0.2  | 93.9                        | 59.7     |
| -0.3                   | 0.7 | 0.3  | 93.9                        | 59.7     |
| -0.2                   | 0.8 | 0.4  | 93.9                        | 59.8     |
| -0.1                   | 0.9 | 0.4  | 93.9                        | 59.8     |
| 0                      | 0.9 | 0.5  | 94                          | 59.8     |
| 0                      | 0.9 | 0.5  | 94                          | 59.9     |
| 0                      | 0.9 | 0.4  | 94.1                        | 59.9     |
| 0                      | 0.9 | 0.3  | 94.1                        | 60.0     |
| 0                      | 0.8 | 0.1  | 94.1                        | 60.0     |
| 0                      | 0.8 | 0    | 94.1                        | 60.0     |
| 0                      | 0.7 | -0.2 | 94.1                        | 60.1     |
| 0.1                    | 0.6 | -0.3 | 94.1                        | 60.1     |
| 0.1                    | 0.5 | -0.4 | 94.1                        | 60.2     |
| 0.2                    | 0.4 | -0.4 | 94                          | 60.2     |
| 0.3                    | 0.3 | -0.4 | 94                          | 60.2     |
| 0.4                    | 0.3 | -0.3 | 94                          | 60.3     |
| 0.4                    | 0.2 | -0.3 | 94                          | 60.3     |
| 0.5                    | 0.1 | -0.2 | 94                          | 60.4     |
| 0.5                    | 0   | -0.1 | 94                          | 60.4     |
| 0.4                    | 0   | -0.1 | 94                          | 60.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.4                    | 0    | 0    | 94                          | 60.5     |
| 0.3                    | 0    | 0    | 94                          | 60.5     |
| 0.1                    | 0.1  | 0    | 94                          | 60.6     |
| 0.1                    | 0.2  | 0    | 94                          | 60.6     |
| 0                      | 0.2  | 0    | 94                          | 60.6     |
| 0                      | 0.3  | 0    | 94                          | 60.7     |
| 0                      | 0.5  | 0    | 94                          | 60.7     |
| 0                      | 0.5  | 0    | 94                          | 60.8     |
| 0                      | 0.6  | 0    | 94                          | 60.8     |
| 0.1                    | 0.7  | 0    | 94                          | 60.8     |
| 0.1                    | 0.7  | 0    | 94                          | 60.9     |
| 0.2                    | 0.6  | 0    | 94                          | 60.9     |
| 0.2                    | 0.6  | 0    | 94                          | 61.0     |
| 0.1                    | 0.5  | 0    | 94                          | 61.0     |
| 0.1                    | 0.4  | 0    | 94                          | 61.0     |
| 0                      | 0.3  | 0    | 94                          | 61.1     |
| -0.1                   | 0.3  | -0.1 | 94                          | 61.1     |
| -0.2                   | 0.2  | -0.2 | 94                          | 61.2     |
| -0.3                   | 0.2  | -0.2 | 94                          | 61.2     |
| -0.3                   | 0.3  | -0.3 | 94                          | 61.2     |
| -0.4                   | 0.3  | -0.3 | 94                          | 61.3     |
| -0.3                   | 0.4  | -0.3 | 93.9                        | 61.3     |
| -0.2                   | 0.4  | -0.2 | 93.9                        | 61.4     |
| -0.1                   | 0.3  | -0.1 | 93.9                        | 61.4     |
| 0.1                    | 0.3  | 0    | 93.9                        | 61.4     |
| 0.2                    | 0.3  | 0.2  | 93.9                        | 61.5     |
| 0.4                    | 0.2  | 0.3  | 93.9                        | 61.5     |
| 0.4                    | 0.1  | 0.4  | 94                          | 61.6     |
| 0.5                    | 0    | 0.5  | 94                          | 61.6     |
| 0.4                    | -0.1 | 0.5  | 94                          | 61.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.4                    | -0.2 | 0.4  | 94.1                        | 61.7     |
| 0.2                    | -0.2 | 0.2  | 94.1                        | 61.7     |
| 0                      | -0.2 | 0.1  | 94.1                        | 61.8     |
| -0.2                   | -0.2 | -0.1 | 94.1                        | 61.8     |
| -0.4                   | -0.2 | -0.3 | 94.1                        | 61.8     |
| -0.6                   | -0.1 | -0.5 | 94.1                        | 61.9     |
| 0                      | 0    | -0.6 | 94                          | 61.9     |
| -0.9                   | 0.1  | -0.7 | 94                          | 62.0     |
| -1                     | 0.2  | -0.7 | 94                          | 62.0     |
| -1                     | 0.2  | -0.6 | 93.9                        | 62.0     |
| -1                     | 0.3  | -0.5 | 93.9                        | 62.1     |
| -0.9                   | 0.4  | -0.3 | 93.8                        | 62.1     |
| -0.8                   | 0.5  | -0.1 | 93.8                        | 62.2     |
| -0.6                   | 0.5  | 0.1  | 93.8                        | 62.2     |
| -0.5                   | 0.5  | 0.4  | 93.8                        | 62.2     |
| -0.3                   | 0.6  | 0.6  | 93.9                        | 62.3     |
| -0.2                   | 0.6  | 0.7  | 93.9                        | 62.3     |
| -0.2                   | 0.6  | 0.7  | 94                          | 62.4     |
| -0.3                   | 0.5  | 0.7  | 94.1                        | 62.4     |
| -0.4                   | 0.5  | 0.5  | 94.1                        | 62.4     |
| -0.5                   | 0.5  | 0.3  | 94.2                        | 62.5     |
| -0.6                   | 0.5  | 0.1  | 94.2                        | 62.5     |
| -0.7                   | 0.4  | -0.2 | 94.2                        | 62.6     |
| -0.8                   | 0.4  | -0.5 | 94.1                        | 62.6     |
| -0.7                   | 0.5  | -0.7 | 94.1                        | 62.6     |
| -0.7                   | 0.5  | -0.9 | 94                          | 62.7     |
| -0.6                   | 0.5  | -0.9 | 94                          | 62.7     |
| -0.5                   | 0.6  | -0.9 | 93.9                        | 62.8     |
| -0.3                   | 0.6  | -0.7 | 93.8                        | 62.8     |
| -0.1                   | 0.6  | -0.5 | 93.1                        | 62.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0                      | 0.7 | -0.3 | 93.8                        | 62.9     |
| 0.2                    | 0.7 | -0.1 | 93.8                        | 62.9     |
| 0.2                    | 0.6 | 0.1  | 93.8                        | 63.0     |
| 0.3                    | 0.6 | 0.3  | 93.9                        | 63.0     |
| 0.2                    | 0.6 | 0.3  | 93.9                        | 63.0     |
| 0.2                    | 0.5 | 0.4  | 93.9                        | 63.1     |
| 0.1                    | 0.4 | 0.3  | 94                          | 63.1     |
| -0.1                   | 0.2 | 0.2  | 94                          | 63.2     |
| -0.2                   | 0.1 | 0.1  | 94                          | 63.2     |
| -0.3                   | 0.1 | 0    | 94                          | 63.2     |
| -0.4                   | 0   | -0.1 | 94                          | 63.3     |
| -0.4                   | 0   | -0.2 | 94                          | 63.3     |
| -0.4                   | 0   | -0.2 | 94                          | 63.4     |
| -0.4                   | 0   | -0.2 | 93.9                        | 63.4     |
| -0.4                   | 0.1 | -0.1 | 93.9                        | 63.4     |
| -0.3                   | 0.1 | -0.1 | 93.9                        | 63.5     |
| -0.2                   | 0.1 | 0    | 93.9                        | 63.5     |
| -0.2                   | 0.2 | 0.1  | 93.9                        | 63.6     |
| -0.1                   | 0.2 | 0.1  | 94                          | 63.6     |
| 0                      | 0.1 | 0.1  | 94                          | 63.6     |
| 0                      | 0.1 | 0.1  | 94                          | 63.7     |
| 0                      | 0.1 | 0.1  | 94                          | 63.7     |
| 0                      | 0.1 | 0    | 94                          | 63.8     |
| -0.1                   | 0.1 | -0.1 | 94                          | 63.8     |
| -0.1                   | 0.1 | -0.1 | 94                          | 63.8     |
| -0.2                   | 0.2 | -0.2 | 94                          | 63.9     |
| -0.2                   | 0.2 | -0.2 | 94                          | 63.9     |
| -0.3                   | 0.3 | -0.2 | 93.9                        | 64.0     |
| -0.3                   | 0.3 | -0.2 | 93.9                        | 64.0     |
| -0.2                   | 0.4 | -0.1 | 93.9                        | 64.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.1                   | 0.4 | -0.1 | 93.9                        | 64.1     |
| 0                      | 0.4 | 0    | 93.9                        | 64.1     |
| 0.1                    | 0.3 | 0    | 93.9                        | 64.2     |
| 0.3                    | 0.3 | 0    | 94                          | 64.2     |
| 0.4                    | 0.3 | 0    | 94                          | 64.2     |
| 0.5                    | 0.2 | 0    | 94                          | 64.3     |
| 0.5                    | 0.2 | 0    | 94                          | 64.3     |
| 0.5                    | 0.3 | -0.1 | 94                          | 64.4     |
| 0.4                    | 0.3 | -0.1 | 94                          | 64.4     |
| 0.3                    | 0.4 | -0.2 | 94                          | 64.4     |
| 0.2                    | 0.5 | -0.2 | 94                          | 64.5     |
| 0.2                    | 0.6 | -0.2 | 94                          | 64.5     |
| 0.1                    | 0.7 | -0.1 | 93.9                        | 64.6     |
| 0                      | 0.8 | -0.1 | 93.9                        | 64.6     |
| 0                      | 0.8 | -0.1 | 93.9                        | 64.6     |
| 0                      | 0.8 | 0    | 93.9                        | 64.7     |
| 0.1                    | 0.3 | 0.1  | 93.9                        | 64.7     |
| 0.2                    | 0.8 | 0.2  | 93.9                        | 64.8     |
| 0.3                    | 0.7 | 0.3  | 94                          | 64.8     |
| 0.4                    | 0.6 | 0.3  | 94                          | 64.8     |
| 0.5                    | 0.6 | 0.3  | 94                          | 64.9     |
| 0.5                    | 0.6 | 0.2  | 94                          | 64.9     |
| 0.5                    | 0.6 | 0.2  | 94.1                        | 65.0     |
| 0.4                    | 0.6 | 0.1  | 94.1                        | 65.0     |
| 0.3                    | 0.6 | 0    | 94.1                        | 65.0     |
| 0.2                    | 0.7 | -0.2 | 94.1                        | 65.1     |
| 0.1                    | 0.7 | -0.3 | 94.1                        | 65.1     |
| 0                      | 0.7 | -0.3 | 94                          | 65.2     |
| -0.2                   | 0.7 | -0.4 | 94                          | 65.2     |
| -0.2                   | 0.7 | -0.4 | 94                          | 65.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.3                   | 0.6  | -0.3 | 93.9                        | 65.3     |
| -0.3                   | 0.6  | -0.2 | 93.9                        | 65.3     |
| -0.2                   | 0.6  | -0.1 | 93.9                        | 65.4     |
| -0.2                   | 0.6  | 0    | 93.9                        | 65.4     |
| -0.1                   | 0.6  | 0.1  | 93.9                        | 65.4     |
| -0.1                   | 0.6  | 0.1  | 93.9                        | 65.5     |
| 0                      | 0.6  | 0.2  | 94                          | 65.5     |
| 0                      | 0.6  | 0.2  | 94                          | 65.6     |
| -0.1                   | 0.7  | 0.2  | 94                          | 65.6     |
| -0.1                   | 0.7  | 0.1  | 94                          | 65.6     |
| -0.2                   | 0.8  | 0    | 94                          | 65.7     |
| -0.3                   | 0.8  | 0    | 94                          | 65.7     |
| -0.5                   | 0.9  | -0.1 | 94                          | 65.8     |
| -0.6                   | 0.9  | -0.2 | 94                          | 65.8     |
| -0.7                   | 0.8  | -0.2 | 94                          | 65.8     |
| -0.7                   | 0.8  | -0.2 | 94                          | 65.9     |
| -0.7                   | 0.7  | -0.2 | 94                          | 65.9     |
| -0.7                   | 0.6  | -0.1 | 94                          | 66.0     |
| -0.6                   | 0.5  | 0    | 94                          | 66.0     |
| -0.5                   | 0.4  | 0    | 94                          | 66.0     |
| -0.4                   | 0.2  | 0.1  | 94                          | 66.1     |
| -0.3                   | 0.1  | 0.2  | 94                          | 66.1     |
| -0.3                   | 0    | 0.2  | 94                          | 66.2     |
| -0.2                   | -0.1 | 0.2  | 94                          | 66.2     |
| -0.2                   | -0.2 | 0.2  | 94                          | 66.2     |
| -0.2                   | -0.2 | 0.1  | 94.1                        | 66.3     |
| -0.2                   | -0.3 | 0    | 94.1                        | 66.3     |
| -0.2                   | -0.2 | -0.1 | 94.1                        | 66.4     |
| -0.2                   | -0.2 | -0.1 | 94.1                        | 66.4     |
| -0.1                   | -0.1 | -0.2 | 94                          | 66.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.1                   | 0    | -0.2 | 94                          | 66.5     |
| 0                      | 0    | -0.2 | 94                          | 66.5     |
| 0                      | 0.1  | -0.2 | 94                          | 66.6     |
| 0                      | 0.2  | -0.2 | 94                          | 66.6     |
| 0                      | 0.2  | -0.2 | 94                          | 66.6     |
| 0                      | 0.3  | -0.2 | 94                          | 66.7     |
| -0.1                   | 0.2  | -0.2 | 94                          | 66.7     |
| -0.1                   | 0.2  | -0.2 | 94                          | 66.8     |
| -0.2                   | 0.2  | -0.2 | 94                          | 66.8     |
| -0.3                   | 0.1  | -0.2 | 94                          | 66.8     |
| -0.4                   | 0.1  | -0.3 | 94                          | 66.9     |
| -0.4                   | 0    | -0.4 | 94                          | 66.9     |
| -0.5                   | 0    | -0.4 | 94                          | 67.0     |
| -0.5                   | 0    | -0.5 | 93.9                        | 67.0     |
| -0.5                   | 0.1  | -0.5 | 93.9                        | 67.0     |
| -0.5                   | 0.1  | -0.5 | 93.9                        | 67.1     |
| -0.4                   | 0.2  | -0.4 | 93.8                        | 67.1     |
| -0.4                   | 0.3  | -0.3 | 93.8                        | 67.2     |
| -0.3                   | 0.4  | -0.1 | 93.8                        | 67.2     |
| -0.2                   | 0.4  | 0.1  | 93.8                        | 67.2     |
| -0.2                   | 0.4  | 0.3  | 93.8                        | 67.3     |
| -0.1                   | 0.3  | 0.5  | 93.8                        | 67.3     |
| -0.1                   | 0.2  | 0.6  | 93.9                        | 67.4     |
| -0.1                   | 0.1  | 0.6  | 93.9                        | 67.4     |
| -0.1                   | 0.1  | 0.6  | 94                          | 67.4     |
| -0.2                   | 0    | 0.4  | 94                          | 67.5     |
| -0.3                   | -0.1 | 0.3  | 94.1                        | 67.5     |
| -0.3                   | -0.1 | 0    | 94.1                        | 67.6     |
| -0.4                   | -0.1 | -0.2 | 94.1                        | 67.6     |
| -0.5                   | -0.1 | -0.4 | 94.1                        | 67.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.5                   | 0   | -0.6 | 94                          | 67.7     |
| -0.5                   | 0.1 | -0.6 | 94                          | 67.7     |
| -0.4                   | 0.2 | -0.7 | 93.9                        | 67.8     |
| -0.3                   | 0.4 | -0.6 | 93.9                        | 67.8     |
| -0.1                   | 0.5 | -0.5 | 93.8                        | 67.8     |
| 0.1                    | 0.5 | -0.3 | 93.8                        | 67.9     |
| 0.3                    | 0.6 | -0.1 | 93.8                        | 67.9     |
| 0.5                    | 0.6 | 0    | 93.8                        | 68.0     |
| 0.6                    | 0.6 | 0.2  | 93.8                        | 68.0     |
| 0.7                    | 0.6 | 0.3  | 93.9                        | 68.0     |
| 0.7                    | 0.6 | 0.4  | 93.9                        | 68.1     |
| 0.7                    | 0.6 | 0.4  | 93.9                        | 68.1     |
| 0.6                    | 0.6 | 0.3  | 94                          | 68.2     |
| 0.4                    | 0.7 | 0.3  | 94                          | 68.2     |
| 0.2                    | 0.7 | 0.2  | 94                          | 68.2     |
| 0                      | 0.8 | 0    | 94                          | 68.3     |
| -0.2                   | 0.9 | -0.1 | 94                          | 68.3     |
| -0.3                   | 1   | -0.2 | 94                          | 68.4     |
| -0.4                   | 1.1 | -0.3 | 94                          | 68.4     |
| -0.4                   | 1.2 | -0.3 | 94                          | 68.4     |
| -0.3                   | 1.2 | -0.2 | 94                          | 68.5     |
| -0.2                   | 1.3 | -0.2 | 93.9                        | 68.5     |
| 0                      | 1.3 | -0.1 | 93.9                        | 68.6     |
| 0.1                    | 1.3 | 0    | 93.9                        | 68.6     |
| 0.3                    | 1.2 | 0.1  | 94                          | 68.6     |
| 0.4                    | 1.2 | 0.2  | 94                          | 68.7     |
| 0.5                    | 1.1 | 0.3  | 94                          | 68.7     |
| 0.5                    | 1.1 | 0.3  | 94                          | 68.8     |
| 0.4                    | 1.1 | 0.2  | 94.1                        | 68.8     |
| 0.3                    | 1.1 | 0.1  | 94.1                        | 68.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.2                    | 1.1  | 0    | 94.1                        | 68.9     |
| 0                      | 1    | -0.2 | 94.1                        | 68.9     |
| -0.1                   | 1    | -0.4 | 94.1                        | 69.0     |
| -0.2                   | 1    | -0.5 | 94.1                        | 69.0     |
| -0.2                   | 0.9  | -0.6 | 94                          | 69.0     |
| -0.2                   | 0.8  | -0.6 | 94                          | 69.1     |
| -0.1                   | 0.7  | -0.6 | 93.9                        | 69.1     |
| 0                      | 0.5  | -0.5 | 93.9                        | 69.2     |
| 0.1                    | 0.4  | -0.4 | 93.9                        | 69.2     |
| 0.2                    | 0.3  | -0.2 | 93.8                        | 69.2     |
| 0.4                    | 0.1  | 0    | 93.8                        | 69.3     |
| 0.5                    | 0    | 0.2  | 93.9                        | 69.3     |
| 0.5                    | 0    | 0.3  | 93.9                        | 69.4     |
| 0.5                    | -0.1 | 0.4  | 93.9                        | 69.4     |
| 0.5                    | -0.1 | 0.4  | 94                          | 69.4     |
| 0.4                    | 0    | 0.4  | 94                          | 69.5     |
| 0.3                    | 0    | 0.2  | 94.1                        | 69.5     |
| 0.1                    | 0.1  | 0.1  | 94.1                        | 69.6     |
| 0                      | 0.2  | -0.1 | 94.1                        | 69.6     |
| -0.2                   | 0.2  | -0.2 | 94                          | 69.6     |
| -0.3                   | 0.3  | -0.3 | 94                          | 69.7     |
| -0.4                   | 0.4  | -0.3 | 94                          | 69.7     |
| -0.5                   | 0.4  | -0.3 | 93.9                        | 69.8     |
| -0.6                   | 0.4  | -0.3 | 94                          | 69.8     |
| -0.6                   | 0.4  | -0.2 | 93.9                        | 69.8     |
| -0.5                   | 0.4  | -0.1 | 93.9                        | 69.9     |
| -0.5                   | 0.3  | 0.1  | 93.9                        | 69.9     |
| -0.4                   | 0.3  | 0.2  | 94                          | 70.0     |
| -0.3                   | 0.2  | 0.3  | 94                          | 70.0     |
| -0.2                   | 0.1  | 0.4  | 94                          | 70.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.2                   | 0    | 0.4  | 94.1                        | 70.1     |
| -0.1                   | 0    | 0.3  | 94.1                        | 70.1     |
| -0.1                   | -0.1 | 0.2  | 94.1                        | 70.2     |
| -0.1                   | -0.1 | 0.1  | 94.1                        | 70.2     |
| -0.1                   | -0.1 | 0    | 94.1                        | 70.2     |
| -0.1                   | 0    | -0.2 | 94.1                        | 70.3     |
| -0.2                   | 0    | -0.3 | 94.1                        | 70.3     |
| -0.2                   | 0.1  | -0.4 | 94.1                        | 70.4     |
| -0.3                   | 0.2  | -0.5 | 94.1                        | 70.4     |
| -0.3                   | 0.2  | -0.6 | 94                          | 70.4     |
| -0.3                   | 0.3  | -0.6 | 94                          | 70.5     |
| -0.3                   | 0.3  | -0.6 | 94                          | 70.5     |
| -0.3                   | 0.3  | -0.5 | 94                          | 70.6     |
| -0.2                   | 0.2  | -0.5 | 93.9                        | 70.6     |
| -0.2                   | 0.2  | -0.5 | 93.9                        | 70.6     |
| -0.2                   | 0.1  | -0.5 | 93.9                        | 70.7     |
| -0.2                   | 0    | -0.4 | 93.9                        | 70.7     |
| -0.1                   | 0    | -0.4 | 93.9                        | 70.8     |
| -0.1                   | 0    | -0.4 | 93.9                        | 70.8     |
| -0.1                   | 0.1  | -0.4 | 93.9                        | 70.8     |
| -0.2                   | 0.1  | -0.3 | 93.8                        | 70.9     |
| -0.2                   | 0.2  | -0.2 | 93.8                        | 70.9     |
| -0.2                   | 0.3  | -0.1 | 93.8                        | 71.0     |
| -0.3                   | 0.4  | 0    | 93.8                        | 71.0     |
| -0.3                   | 0.4  | 0.2  | 93.8                        | 71.0     |
| -0.3                   | 0.4  | 0.3  | 93.9                        | 71.1     |
| -0.4                   | 0.5  | 0.4  | 93.9                        | 71.1     |
| -0.4                   | 0.5  | 0.5  | 93.9                        | 71.2     |
| -0.4                   | 0.5  | 0.4  | 93.9                        | 71.2     |
| -0.5                   | 0.5  | 0.4  | 94                          | 71.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.5                   | 0.5 | 0.3  | 94                          | 71.3     |
| -0.5                   | 0.5 | 0.1  | 94                          | 71.3     |
| -0.4                   | 0.5 | 0    | 94                          | 71.4     |
| -0.4                   | 0.6 | -0.1 | 94                          | 71.4     |
| -0.4                   | 0.6 | -0.2 | 94                          | 71.4     |
| -0.4                   | 0.7 | -0.3 | 94                          | 71.5     |
| -0.3                   | 0.8 | -0.4 | 94                          | 71.5     |
| -0.3                   | 0.9 | -0.4 | 93.9                        | 71.6     |
| -0.2                   | 0.9 | -0.3 | 93.9                        | 71.6     |
| -0.2                   | 1   | -0.2 | 93.9                        | 71.6     |
| -0.1                   | 1   | -0.1 | 93.9                        | 71.7     |
| 0                      | 0.9 | 0    | 93.9                        | 71.7     |
| 0                      | 0.9 | 0.1  | 93.9                        | 71.8     |
| 0                      | 0.8 | 0.1  | 94                          | 71.8     |
| 0                      | 0.7 | 0.1  | 94                          | 71.8     |
| 0                      | 0.6 | 0.1  | 94                          | 71.9     |
| 0                      | 0.5 | 0.1  | 94                          | 71.9     |
| 0                      | 0.4 | 0    | 94                          | 72.0     |
| -0.1                   | 0.4 | -0.1 | 94                          | 72.0     |
| -0.1                   | 0.4 | -0.3 | 94                          | 72.0     |
| -0.2                   | 0.4 | -0.4 | 94                          | 72.1     |
| -0.2                   | 0.4 | -0.5 | 94                          | 72.1     |
| -0.1                   | 0.5 | -0.5 | 94                          | 72.2     |
| -0.1                   | 0.5 | -0.5 | 93.9                        | 72.2     |
| 0                      | 0.5 | -0.5 | 93.9                        | 72.2     |
| 0.1                    | 0.6 | -0.4 | 93.9                        | 72.3     |
| 0.2                    | 0.6 | -0.2 | 93.9                        | 72.3     |
| 0.3                    | 0.6 | -0.1 | 93.9                        | 72.4     |
| 0.3                    | 0.6 | 0    | 93.9                        | 72.4     |
| 0.4                    | 0.6 | 0.2  | 93.9                        | 72.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.4                    | 0.6 | 0.2  | 93.9                        | 72.5     |
| 0.5                    | 0.6 | 0.3  | 94                          | 72.5     |
| 0.4                    | 0.6 | 0.2  | 94                          | 72.6     |
| 0.4                    | 0.6 | 0.2  | 94                          | 72.6     |
| 0.3                    | 0.7 | 0.1  | 94                          | 72.6     |
| 0.3                    | 0.8 | -0.1 | 94                          | 72.7     |
| 0.2                    | 0.9 | -0.2 | 94                          | 72.7     |
| 0.1                    | 0.8 | -0.3 | 94                          | 72.8     |
| 0.1                    | 0.9 | -0.4 | 94                          | 72.8     |
| 0.1                    | 0.8 | -0.4 | 94                          | 72.8     |
| 0.2                    | 0.8 | -0.4 | 93.9                        | 72.9     |
| 0.3                    | 0.7 | -0.4 | 93.9                        | 72.9     |
| 0.3                    | 0.6 | -0.3 | 93.9                        | 73.0     |
| 0.4                    | 0.5 | -0.2 | 93.9                        | 73.0     |
| 0.5                    | 0.4 | -0.1 | 93.9                        | 73.0     |
| 0.6                    | 0.3 | 0.1  | 93.9                        | 73.1     |
| 0.6                    | 0.2 | 0.1  | 93.9                        | 73.1     |
| 0.6                    | 0.1 | 0.2  | 94                          | 73.2     |
| 0.5                    | 0.1 | 0.2  | 94                          | 73.2     |
| 0.4                    | 0.1 | 0.2  | 94                          | 73.2     |
| 0.2                    | 0.1 | 0.1  | 94                          | 73.3     |
| 0.1                    | 0.1 | 0    | 94                          | 73.3     |
| -0.1                   | 0.1 | 0    | 94                          | 73.4     |
| -0.2                   | 0.2 | -0.1 | 94                          | 73.4     |
| -0.4                   | 0.3 | -0.1 | 94                          | 73.4     |
| -0.4                   | 0.3 | -0.1 | 94                          | 73.5     |
| -0.5                   | 0.4 | -0.1 | 94                          | 73.5     |
| -0.5                   | 0.5 | -0.1 | 94                          | 73.6     |
| -0.4                   | 0.5 | -0.1 | 94                          | 73.6     |
| -0.3                   | 0.5 | 0    | 94                          | 73.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.2                   | 0.5 | 0    | 94                          | 73.7     |
| -0.1                   | 0.5 | 0    | 94                          | 73.7     |
| -0.1                   | 0.4 | 0    | 94                          | 73.8     |
| -0.1                   | 0.3 | 0    | 94                          | 73.8     |
| -0.1                   | 0.3 | -0.1 | 94.1                        | 73.8     |
| -0.1                   | 0.2 | -0.2 | 94.1                        | 73.9     |
| -0.1                   | 0.2 | -0.3 | 94.1                        | 73.9     |
| -0.2                   | 0.2 | -0.3 | 94                          | 74.0     |
| -0.3                   | 0.2 | -0.4 | 94                          | 74.0     |
| -0.3                   | 0.2 | -0.4 | 94                          | 74.0     |
| -0.3                   | 0.3 | -0.4 | 94                          | 74.1     |
| -0.3                   | 0.4 | -0.4 | 93.9                        | 74.1     |
| -0.2                   | 0.5 | -0.4 | 93.9                        | 74.2     |
| -0.2                   | 0.6 | -0.3 | 93.9                        | 74.2     |
| 0                      | 0.7 | -0.2 | 93.9                        | 74.2     |
| 0.1                    | 0.7 | 0    | 93.9                        | 74.3     |
| 0.2                    | 0.8 | 0.1  | 93.9                        | 74.3     |
| 0.2                    | 0.8 | 0.1  | 93.9                        | 74.4     |
| 0.2                    | 0.8 | 0.2  | 94                          | 74.4     |
| 0.2                    | 0.8 | 0.2  | 94                          | 74.4     |
| 0.1                    | 0.8 | 0.2  | 94                          | 74.5     |
| -0.1                   | 0.8 | 0.1  | 94                          | 74.5     |
| -0.3                   | 0.8 | 0    | 94.1                        | 74.6     |
| -0.4                   | 0.7 | -0.2 | 94.1                        | 74.6     |
| -0.6                   | 0.8 | -0.3 | 94.1                        | 74.6     |
| -0.7                   | 0.8 | -0.5 | 94                          | 74.7     |
| -0.8                   | 0.8 | -0.6 | 94                          | 74.7     |
| -0.8                   | 0.8 | -0.6 | 94                          | 74.8     |
| -0.8                   | 0.8 | -0.6 | 93.9                        | 74.8     |
| -0.7                   | 0.7 | -0.5 | 93.9                        | 74.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.6                   | 0.7  | -0.4 | 93.9                        | 74.9     |
| -0.5                   | 0.6  | -0.3 | 93.9                        | 74.9     |
| -0.4                   | 0.5  | -0.1 | 93.9                        | 75.0     |
| -0.3                   | 0.4  | 0.1  | 93.9                        | 75.0     |
| -0.2                   | 0.3  | 0.2  | 93.9                        | 75.0     |
| -0.1                   | 0.2  | 0.3  | 93.9                        | 75.1     |
| -0.1                   | 0.2  | 0.4  | 94                          | 75.1     |
| -0.1                   | 0.2  | 0.4  | 94                          | 75.2     |
| -0.2                   | 0.1  | 0.3  | 94                          | 75.2     |
| -0.2                   | 0.1  | 0.1  | 94.1                        | 75.2     |
| -0.3                   | 0.1  | 0    | 94.1                        | 75.3     |
| -0.4                   | 0.1  | -0.3 | 94.1                        | 75.3     |
| -0.4                   | 0.1  | -0.4 | 94.1                        | 75.4     |
| -0.4                   | 0.1  | -0.6 | 94                          | 75.4     |
| -0.5                   | 0.1  | -0.7 | 94                          | 75.4     |
| -0.4                   | 0    | -0.7 | 94                          | 75.5     |
| -0.4                   | 0    | -0.7 | 93.9                        | 75.5     |
| -0.3                   | -0.1 | -0.7 | 93.9                        | 75.6     |
| -0.2                   | -0.1 | -0.6 | 93.9                        | 75.6     |
| -0.1                   | -0.1 | -0.5 | 93.9                        | 75.6     |
| 0                      | 0    | -0.4 | 93.8                        | 75.7     |
| 0.1                    | 0    | -0.2 | 93.8                        | 75.7     |
| 0.1                    | 0.1  | -0.1 | 93.8                        | 75.8     |
| 0.1                    | 0.2  | -0.1 | 93.9                        | 75.8     |
| 0.2                    | 0.4  | 0    | 93.9                        | 75.8     |
| 0.1                    | 0.5  | 0    | 93.9                        | 75.9     |
| 0.1                    | 0.6  | 0    | 93.9                        | 75.9     |
| 0                      | 0.7  | 0.1  | 93.9                        | 76.0     |
| 0                      | 0.7  | 0    | 93.9                        | 76.0     |
| -0.1                   | 0.7  | 0    | 93.9                        | 76.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.1                   | 0.7 | 0    | 93.9                        | 76.1     |
| -0.2                   | 0.6 | 0.1  | 93.9                        | 76.1     |
| -0.2                   | 0.5 | 0.1  | 94                          | 76.2     |
| -0.1                   | 0.4 | 0.1  | 94                          | 76.2     |
| -0.1                   | 0.3 | 0.1  | 93.9                        | 76.2     |
| 0                      | 0.2 | 0.1  | 94                          | 76.3     |
| 0.1                    | 0.2 | 0.1  | 94                          | 76.3     |
| 0.2                    | 0.2 | 0    | 94                          | 76.4     |
| 0.3                    | 0.2 | -0.1 | 94.1                        | 76.4     |
| 0.4                    | 0.3 | -0.2 | 94.1                        | 76.4     |
| 0.4                    | 0.4 | -0.3 | 94.1                        | 76.5     |
| 0.4                    | 0.5 | -0.4 | 94.1                        | 76.5     |
| 0.4                    | 0.6 | -0.4 | 94                          | 76.6     |
| 0.4                    | 0.7 | -0.5 | 94                          | 76.6     |
| 0.4                    | 0.8 | -0.5 | 94                          | 76.6     |
| 0.4                    | 0.9 | -0.5 | 94                          | 76.7     |
| 0.4                    | 1   | -0.5 | 93.9                        | 76.7     |
| 0.4                    | 1   | -0.4 | 93.9                        | 76.8     |
| 0.3                    | 0.9 | -0.4 | 93.9                        | 76.8     |
| 0.3                    | 0.9 | -0.3 | 93.9                        | 76.8     |
| 0.3                    | 0.8 | -0.2 | 93.9                        | 76.9     |
| 0.3                    | 0.7 | -0.1 | 93.9                        | 76.9     |
| 0.3                    | 0.6 | -0.1 | 93.9                        | 77.0     |
| 0.3                    | 0.5 | -0.1 | 93.9                        | 77.0     |
| 0.2                    | 0.4 | -0.1 | 93.9                        | 77.0     |
| 0.2                    | 0.3 | -0.1 | 93.9                        | 77.1     |
| 0.1                    | 0.4 | -0.1 | 94                          | 77.1     |
| 0                      | 0.4 | -0.2 | 94                          | 77.2     |
| -0.1                   | 0.5 | -0.2 | 93.9                        | 77.2     |
| -0.1                   | 0.6 | -0.2 | 93.9                        | 77.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.2                   | 0.8 | -0.2 | 93.9                        | 77.3     |
| -0.2                   | 0.9 | -0.2 | 93.9                        | 77.3     |
| -0.2                   | 1.1 | -0.2 | 93.9                        | 77.4     |
| -0.2                   | 1.2 | -0.1 | 93.9                        | 77.4     |
| -0.2                   | 1.2 | -0.1 | 93.9                        | 77.4     |
| -0.2                   | 1.3 | 0    | 93.9                        | 77.5     |
| -0.2                   | 1.2 | 0.1  | 93.9                        | 77.5     |
| -0.1                   | 1.2 | 0.1  | 94                          | 77.6     |
| -0.1                   | 1.1 | 0.2  | 94                          | 77.6     |
| -0.2                   | 1   | 0.2  | 94                          | 77.6     |
| -0.2                   | 0.9 | 0.3  | 94                          | 77.7     |
| -0.2                   | 0.8 | 0.2  | 94.1                        | 77.7     |
| -0.2                   | 0.7 | 0.1  | 94.1                        | 77.8     |
| -0.3                   | 0.6 | 0.1  | 94.1                        | 77.8     |
| -0.3                   | 0.6 | 0    | 94.1                        | 77.8     |
| -0.2                   | 0.5 | -0.1 | 94.1                        | 77.9     |
| -0.2                   | 0.5 | -0.2 | 94.1                        | 77.9     |
| -0.1                   | 0.5 | -0.3 | 94.1                        | 78.0     |
| -0.1                   | 0.5 | -0.3 | 94.1                        | 78.0     |
| 0                      | 0.5 | -0.4 | 94.1                        | 78.0     |
| 0.1                    | 0.4 | -0.4 | 94.1                        | 78.1     |
| 0.1                    | 0.4 | -0.4 | 94.1                        | 78.1     |
| 0.2                    | 0.4 | -0.4 | 94                          | 78.2     |
| 0.2                    | 0.4 | -0.3 | 94                          | 78.2     |
| 0.1                    | 0.4 | -0.4 | 94                          | 78.2     |
| 0.1                    | 0.4 | -0.4 | 94                          | 78.3     |
| 0.1                    | 0.4 | -0.3 | 94                          | 78.3     |
| 0                      | 0.4 | -0.4 | 94                          | 78.4     |
| -0.1                   | 0.4 | -0.5 | 94                          | 78.4     |
| -0.1                   | 0.4 | -0.5 | 94                          | 78.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.2                   | 0.4  | -0.5 | 94                          | 78.5     |
| -0.3                   | 0.4  | -0.5 | 94                          | 78.5     |
| -0.3                   | 0.3  | -0.5 | 93.9                        | 78.6     |
| -0.3                   | 0.3  | -0.5 | 93.9                        | 78.6     |
| -0.3                   | 0.3  | -0.4 | 93.9                        | 78.6     |
| -0.4                   | 0.2  | -0.3 | 93.9                        | 78.7     |
| -0.4                   | 0.2  | -0.2 | 93.9                        | 78.7     |
| -0.4                   | 0.1  | -0.1 | 93.9                        | 78.8     |
| -0.4                   | 0    | 0    | 93.9                        | 78.8     |
| -0.4                   | 0    | 0    | 93.9                        | 78.8     |
| -0.4                   | -0.1 | 0    | 93.9                        | 78.9     |
| -0.5                   | -0.1 | 0    | 94                          | 78.9     |
| -0.5                   | -0.1 | 0    | 94                          | 79.0     |
| -0.5                   | -0.1 | -0.1 | 94                          | 79.0     |
| -0.6                   | 0    | -0.2 | 94                          | 79.0     |
| -0.6                   | 0    | -0.3 | 94                          | 79.1     |
| -0.5                   | 0.1  | -0.4 | 94                          | 79.1     |
| -0.6                   | 0.1  | -0.4 | 94                          | 79.2     |
| -0.5                   | 0.2  | -0.4 | 93.9                        | 79.2     |
| -0.5                   | 0.2  | -0.4 | 93.9                        | 79.2     |
| -0.4                   | 0.2  | -0.3 | 93.9                        | 79.3     |
| -0.3                   | 0.2  | -0.2 | 93.9                        | 79.3     |
| -0.1                   | 0.2  | -0.2 | 93.9                        | 79.4     |
| 0                      | 0.1  | -0.1 | 93.9                        | 79.4     |
| 0.1                    | 0.1  | 0    | 93.9                        | 79.4     |
| 0.1                    | 0    | 0    | 94                          | 79.5     |
| 0.1                    | 0    | 0    | 94                          | 79.5     |
| 0.1                    | 0    | -0.1 | 94                          | 79.6     |
| 0.1                    | 0    | -0.1 | 94                          | 79.6     |
| 0                      | 0    | -0.2 | 94                          | 79.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.1                   | 0.1 | -0.3 | 94                          | 79.7     |
| -0.2                   | 0.1 | -0.4 | 94                          | 79.7     |
| -0.3                   | 0.2 | -0.5 | 94                          | 79.8     |
| -0.3                   | 0.3 | -0.5 | 94                          | 79.8     |
| -0.4                   | 0.4 | -0.5 | 93.9                        | 79.8     |
| -0.4                   | 0.4 | -0.5 | 93.9                        | 79.9     |
| -0.3                   | 0.5 | -0.4 | 93.9                        | 79.9     |
| -0.2                   | 0.6 | -0.3 | 93.9                        | 80.0     |
| -0.1                   | 0.6 | -0.2 | 93.9                        | 80.0     |
| 0                      | 0.7 | -0.1 | 93.9                        | 80.0     |
| 0.1                    | 0.7 | 0    | 93.9                        | 80.1     |
| 0.2                    | 0.8 | 0.1  | 93.9                        | 80.1     |
| 0.2                    | 0.4 | 0.1  | 94                          | 80.2     |
| 0.3                    | 0.9 | 0.1  | 94                          | 80.2     |
| 0.2                    | 0.9 | 0.1  | 94                          | 80.2     |
| 0.1                    | 1   | 0    | 94                          | 80.3     |
| 0                      | 1   | -0.2 | 94                          | 80.3     |
| -0.1                   | 1.1 | -0.3 | 94                          | 80.4     |
| -0.2                   | 1.1 | -0.5 | 94                          | 80.4     |
| -0.3                   | 1.2 | -0.6 | 94                          | 80.4     |
| -0.3                   | 1.2 | -0.7 | 94                          | 80.5     |
| -0.3                   | 1.2 | -0.7 | 93.9                        | 80.5     |
| -0.3                   | 1.2 | -0.7 | 93.9                        | 80.6     |
| -0.2                   | 1.2 | -0.6 | 93.9                        | 80.6     |
| -0.1                   | 1.2 | -0.5 | 93.8                        | 80.6     |
| 0.1                    | 1.2 | -0.4 | 93.8                        | 80.7     |
| 0.2                    | 1.1 | -0.2 | 93.8                        | 80.7     |
| 0.4                    | 1.1 | -0.1 | 93.9                        | 80.8     |
| 0.5                    | 1   | 0    | 93.9                        | 80.8     |
| 0.6                    | 0.9 | 0    | 93.9                        | 80.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.7                    | 0.9 | 0    | 93.9                        | 80.9     |
| 0.7                    | 0.8 | 0    | 93.9                        | 80.9     |
| 0.6                    | 0.8 | -0.1 | 94                          | 81.0     |
| 0.5                    | 0.7 | -0.1 | 94                          | 81.0     |
| 0.4                    | 0.7 | -0.1 | 94                          | 81.0     |
| 0.2                    | 0.6 | -0.2 | 94                          | 81.1     |
| 0.1                    | 0.6 | -0.2 | 94                          | 81.1     |
| 0                      | 0.6 | -0.1 | 94                          | 81.2     |
| -0.2                   | 0.6 | -0.1 | 94                          | 81.2     |
| -0.3                   | 0.5 | -0.1 | 94                          | 81.2     |
| -0.3                   | 0.5 | 0    | 94                          | 81.3     |
| -0.3                   | 0.5 | 0    | 94                          | 81.3     |
| -0.3                   | 0.5 | 0.1  | 94                          | 81.4     |
| -0.1                   | 0.5 | 0.1  | 94                          | 81.4     |
| -0.1                   | 0.5 | 0    | 94.1                        | 81.4     |
| 0                      | 0.5 | 0    | 94.1                        | 81.5     |
| 0                      | 0.5 | -0.1 | 94.1                        | 81.5     |
| 0.1                    | 0.5 | -0.2 | 94.1                        | 81.6     |
| 0.1                    | 0.5 | -0.3 | 94.1                        | 81.6     |
| 0.1                    | 0.4 | -0.4 | 94.1                        | 81.6     |
| 0.1                    | 0.4 | -0.4 | 94.1                        | 81.7     |
| 0.1                    | 0.4 | -0.5 | 94                          | 81.7     |
| 0                      | 0.3 | -0.5 | 94                          | 81.8     |
| 0                      | 0.3 | -0.5 | 94                          | 81.8     |
| 0                      | 0.2 | -0.4 | 94                          | 81.8     |
| -0.1                   | 0.2 | -0.4 | 94                          | 81.9     |
| -0.1                   | 0.2 | -0.3 | 94                          | 81.9     |
| -0.1                   | 0.2 | -0.3 | 94                          | 82.0     |
| -0.1                   | 0.2 | -0.2 | 94                          | 82.0     |
| 0                      | 0.2 | -0.2 | 94                          | 82.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0                      | 0.2 | -0.2 | 94                          | 82.1     |
| 0                      | 0.2 | -0.2 | 94                          | 82.1     |
| 0                      | 0.2 | -0.1 | 94                          | 82.2     |
| 0                      | 0.3 | -0.2 | 94                          | 82.2     |
| -0.1                   | 0.3 | -0.3 | 94                          | 82.2     |
| -0.1                   | 0.4 | -0.4 | 94                          | 82.3     |
| -0.1                   | 0.4 | -0.4 | 94                          | 82.3     |
| -0.1                   | 0.5 | -0.5 | 94                          | 82.4     |
| -0.2                   | 0.5 | -0.5 | 94                          | 82.4     |
| -0.2                   | 0.6 | -0.6 | 94                          | 82.4     |
| -0.2                   | 0.6 | -0.5 | 93.9                        | 82.5     |
| -0.2                   | 0.5 | -0.5 | 93.9                        | 82.5     |
| -0.2                   | 0.5 | -0.4 | 93.9                        | 82.6     |
| -0.2                   | 0.4 | -0.3 | 93.9                        | 82.6     |
| -0.2                   | 0.3 | -0.2 | 93.9                        | 82.6     |
| -0.3                   | 0.2 | -0.1 | 93.9                        | 82.7     |
| -0.3                   | 0.1 | -0.1 | 93.9                        | 82.7     |
| -0.3                   | 0.1 | -0.1 | 93.9                        | 82.8     |
| -0.3                   | 0   | 0    | 94                          | 82.8     |
| -0.4                   | 0   | 0    | 94                          | 82.8     |
| -0.4                   | 0   | -0.1 | 94                          | 82.9     |
| -0.4                   | 0.1 | -0.1 | 94                          | 82.9     |
| -0.3                   | 0.1 | -0.2 | 94                          | 83.0     |
| -0.3                   | 0.2 | -0.2 | 94                          | 83.0     |
| -0.3                   | 0.3 | -0.3 | 94                          | 83.0     |
| -0.3                   | 0.3 | -0.3 | 94                          | 83.1     |
| -0.2                   | 0.4 | -0.3 | 94                          | 83.1     |
| -0.2                   | 0.4 | -0.3 | 94                          | 83.2     |
| -0.2                   | 0.4 | -0.3 | 94                          | 83.2     |
| -0.2                   | 0.4 | -0.3 | 94                          | 83.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.3                   | 0.4 | -0.4 | 94                          | 83.3     |
| -0.3                   | 0.4 | -0.4 | 94                          | 83.3     |
| -0.4                   | 0.4 | -0.4 | 94                          | 83.4     |
| -0.5                   | 0.4 | -0.4 | 94                          | 83.4     |
| -0.6                   | 0.4 | -0.4 | 94                          | 83.4     |
| -0.7                   | 0.5 | -0.5 | 93.9                        | 83.5     |
| -0.7                   | 0.6 | -0.5 | 93.9                        | 83.5     |
| -0.8                   | 0.7 | -0.5 | 93.9                        | 83.6     |
| -0.8                   | 0.8 | -0.5 | 93.9                        | 83.6     |
| -0.7                   | 1   | -0.5 | 93.9                        | 83.6     |
| -0.6                   | 1.1 | -0.4 | 93.9                        | 83.7     |
| -0.5                   | 1.1 | -0.4 | 93.9                        | 83.7     |
| -0.4                   | 1.1 | -0.3 | 93.9                        | 83.8     |
| -0.3                   | 1.1 | -0.2 | 93.9                        | 83.8     |
| -0.2                   | 1   | 0    | 93.9                        | 83.8     |
| -0.1                   | 0.9 | 0.1  | 93.9                        | 83.9     |
| 0                      | 0.8 | 0.1  | 93.9                        | 83.9     |
| 0                      | 0.6 | 0.2  | 94                          | 84.0     |
| 0                      | 0.5 | 0.2  | 94                          | 84.0     |
| 0                      | 0.4 | 0.1  | 94                          | 84.0     |
| 0                      | 0.4 | 0    | 94.1                        | 84.1     |
| 0                      | 0.4 | -0.1 | 94.1                        | 84.1     |
| -0.1                   | 0.4 | -0.3 | 94.1                        | 84.2     |
| -0.1                   | 0.5 | -0.5 | 94.1                        | 84.2     |
| 0                      | 0.6 | -0.6 | 94.1                        | 84.2     |
| 0                      | 0.6 | -0.7 | 94                          | 84.3     |
| 0.1                    | 0.7 | -0.8 | 94                          | 84.3     |
| 0.2                    | 0.7 | -0.8 | 93.9                        | 84.4     |
| 0.3                    | 0.8 | -0.8 | 93.9                        | 84.4     |
| 0.4                    | 0.8 | -0.7 | 93.9                        | 84.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.5                    | 0.8 | -0.6 | 93.9                        | 84.5     |
| 0.5                    | 0.7 | -0.5 | 93.9                        | 84.5     |
| 0.6                    | 0.7 | -0.3 | 93.9                        | 84.6     |
| 0.6                    | 0.6 | -0.2 | 93.9                        | 84.6     |
| 0.5                    | 0.6 | -0.1 | 93.9                        | 84.6     |
| 0.4                    | 0.5 | 0    | 93.9                        | 84.7     |
| 0.3                    | 0.5 | 0    | 93.9                        | 84.7     |
| 0.2                    | 0.4 | 0    | 93.9                        | 84.8     |
| 0.1                    | 0.4 | -0.1 | 94                          | 84.8     |
| -0.1                   | 0.3 | -0.1 | 94                          | 84.8     |
| -0.2                   | 0.3 | -0.2 | 94                          | 84.9     |
| -0.3                   | 0.3 | -0.3 | 94                          | 84.9     |
| -0.3                   | 0.3 | -0.3 | 94                          | 85.0     |
| -0.3                   | 0.4 | -0.3 | 94                          | 85.0     |
| -0.3                   | 0.4 | -0.3 | 93.9                        | 85.0     |
| -0.2                   | 0.5 | -0.3 | 93.9                        | 85.1     |
| -0.2                   | 0.5 | -0.3 | 93.9                        | 85.1     |
| -0.1                   | 0.6 | -0.2 | 93.9                        | 85.2     |
| 0                      | 0.6 | -0.2 | 94                          | 85.2     |
| 0.1                    | 0.6 | -0.1 | 94                          | 85.2     |
| 0.2                    | 0.6 | -0.1 | 94                          | 85.3     |
| 0.2                    | 0.6 | -0.1 | 94                          | 85.3     |
| 0.2                    | 0.6 | -0.1 | 94                          | 85.4     |
| 0.1                    | 0.6 | -0.1 | 94                          | 85.4     |
| 0.1                    | 0.5 | -0.2 | 94                          | 85.4     |
| 0                      | 0.5 | -0.3 | 94                          | 85.5     |
| -0.1                   | 0.5 | -0.3 | 94                          | 85.5     |
| -0.1                   | 0.4 | -0.3 | 94                          | 85.6     |
| -0.1                   | 0.4 | -0.4 | 94                          | 85.6     |
| -0.1                   | 0.4 | -0.4 | 94                          | 85.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0                      | 0.3 | -0.4 | 94                          | 85.7     |
| 0.1                    | 0.3 | -0.4 | 94                          | 85.7     |
| 0.2                    | 0.3 | -0.4 | 94                          | 85.8     |
| 0.3                    | 0.3 | -0.3 | 94                          | 85.8     |
| 0.3                    | 0.3 | -0.3 | 94                          | 85.8     |
| 0.4                    | 0.4 | -0.3 | 94                          | 85.9     |
| 0.4                    | 0.4 | -0.3 | 94                          | 85.9     |
| 0.4                    | 0.4 | -0.3 | 94                          | 86.0     |
| 0.4                    | 0.5 | -0.3 | 94                          | 86.0     |
| 0.3                    | 0.5 | -0.3 | 94                          | 86.0     |
| 0.2                    | 0.6 | -0.4 | 94                          | 86.1     |
| 0                      | 0.7 | -0.4 | 94                          | 86.1     |
| -0.1                   | 0.8 | -0.4 | 94                          | 86.2     |
| -0.2                   | 0.8 | -0.4 | 94                          | 86.2     |
| -0.3                   | 0.9 | -0.4 | 94                          | 86.2     |
| -0.4                   | 1   | -0.3 | 93.9                        | 86.3     |
| -0.5                   | 1   | -0.3 | 93.9                        | 86.3     |
| -0.5                   | 1   | -0.2 | 93.9                        | 86.4     |
| -0.5                   | 1   | -0.1 | 93.9                        | 86.4     |
| -0.5                   | 1   | 0    | 94                          | 86.4     |
| -0.4                   | 1   | 0    | 94                          | 86.5     |
| -0.4                   | 0.9 | 0    | 94                          | 86.5     |
| -0.4                   | 0.9 | 0    | 94                          | 86.6     |
| -0.4                   | 0.8 | -0.1 | 94.1                        | 86.6     |
| -0.3                   | 0.7 | -0.2 | 94.1                        | 86.6     |
| -0.4                   | 0.7 | -0.3 | 94.1                        | 86.7     |
| -0.4                   | 0.6 | -0.4 | 94.1                        | 86.7     |
| -0.4                   | 0.6 | -0.5 | 94                          | 86.8     |
| -0.5                   | 0.6 | -0.6 | 94                          | 86.8     |
| -0.5                   | 0.6 | -0.7 | 94                          | 86.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.5                   | 0.6 | -0.7 | 94                          | 86.9     |
| -0.5                   | 0.5 | -0.6 | 94                          | 86.9     |
| -0.5                   | 0.5 | -0.6 | 93.9                        | 87.0     |
| -0.5                   | 0.4 | -0.5 | 93.9                        | 87.0     |
| -0.5                   | 0.3 | -0.4 | 93.9                        | 87.0     |
| -0.4                   | 0.2 | -0.3 | 93.9                        | 87.1     |
| -0.3                   | 0.2 | -0.2 | 93.9                        | 87.1     |
| -0.3                   | 0.1 | -0.1 | 93.9                        | 87.2     |
| -0.2                   | 0   | -0.1 | 93.9                        | 87.2     |
| -0.2                   | 0   | -0.1 | 94                          | 87.2     |
| -0.2                   | 0   | -0.1 | 94                          | 87.3     |
| -0.2                   | 0   | -0.2 | 94                          | 87.3     |
| -0.3                   | 0.1 | -0.2 | 94                          | 87.4     |
| -0.3                   | 0.1 | -0.3 | 94                          | 87.4     |
| -0.4                   | 0.2 | -0.4 | 94                          | 87.4     |
| -0.5                   | 0.2 | -0.5 | 94                          | 87.5     |
| -0.5                   | 0.2 | -0.5 | 94                          | 87.5     |
| -0.5                   | 0.2 | -0.5 | 93.9                        | 87.6     |
| -0.5                   | 0.2 | -0.5 | 93.9                        | 87.6     |
| -0.5                   | 0.2 | -0.5 | 93.9                        | 87.6     |
| -0.4                   | 0.2 | -0.4 | 93.9                        | 87.7     |
| -0.4                   | 0.2 | -0.3 | 93.9                        | 87.7     |
| -0.3                   | 0.2 | -0.2 | 93.9                        | 87.8     |
| -0.2                   | 0.2 | -0.1 | 93.9                        | 87.8     |
| -0.2                   | 0.2 | 0    | 93.9                        | 87.8     |
| -0.1                   | 0.3 | 0    | 93.9                        | 87.9     |
| -0.1                   | 0.3 | 0.1  | 94                          | 87.9     |
| 0                      | 0.4 | 0.1  | 94                          | 88.0     |
| 0                      | 0.4 | 0    | 94                          | 88.0     |
| 0                      | 0.5 | 0    | 94                          | 88.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0                      | 0.5 | -0.1 | 94.1                        | 88.1     |
| 0                      | 0.6 | -0.2 | 94.1                        | 88.1     |
| 0                      | 0.6 | -0.3 | 94.1                        | 88.2     |
| 0                      | 0.6 | -0.4 | 94.1                        | 88.2     |
| 0                      | 0.6 | -0.5 | 94                          | 88.2     |
| 0                      | 0.6 | -0.6 | 94                          | 88.3     |
| 0                      | 0.6 | -0.7 | 94                          | 88.3     |
| 0                      | 0.5 | -0.7 | 94                          | 88.4     |
| 0                      | 0.5 | -0.8 | 94                          | 88.4     |
| 0                      | 0.4 | -0.8 | 93.9                        | 88.4     |
| 0                      | 0.4 | -0.8 | 93.9                        | 88.5     |
| 0                      | 0.3 | -0.7 | 93.9                        | 88.5     |
| 0                      | 0.3 | -0.7 | 93.9                        | 88.6     |
| 0                      | 0.3 | -0.6 | 93.8                        | 88.6     |
| 0                      | 0.3 | -0.5 | 93.9                        | 88.6     |
| 0.1                    | 0.4 | -0.4 | 93.8                        | 88.7     |
| 0.1                    | 0.4 | -0.3 | 93.8                        | 88.7     |
| 0.1                    | 0.4 | -0.2 | 93.8                        | 88.8     |
| 0.1                    | 0.5 | 0    | 93.7                        | 88.8     |
| 0.1                    | 0.5 | 0.1  | 93.8                        | 88.8     |
| 0.1                    | 0.5 | 0.1  | 93.9                        | 88.9     |
| 0.1                    | 0.6 | 0.2  | 93.9                        | 88.9     |
| 0.1                    | 0.6 | 0.2  | 93.9                        | 89.0     |
| 0.1                    | 0.6 | 0.1  | 94                          | 89.0     |
| 0.1                    | 0.6 | 0.1  | 94                          | 89.0     |
| 0                      | 0.6 | 0    | 94                          | 89.1     |
| -0.1                   | 0.7 | -0.1 | 94                          | 89.1     |
| -0.1                   | 0.7 | -0.2 | 94                          | 89.2     |
| -0.2                   | 0.8 | -0.3 | 94                          | 89.2     |
| -0.2                   | 0.8 | -0.4 | 94                          | 89.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.2                   | 0.9 | -0.4 | 94                          | 89.3     |
| -0.2                   | 1   | -0.5 | 94                          | 89.3     |
| -0.2                   | 1.1 | -0.4 | 94                          | 89.4     |
| -0.1                   | 1.1 | -0.4 | 94                          | 89.4     |
| -0.1                   | 1.2 | -0.3 | 94                          | 89.4     |
| 0                      | 1.2 | -0.3 | 94                          | 89.5     |
| 0.1                    | 1.3 | -0.2 | 94                          | 89.5     |
| 0.2                    | 1.2 | -0.1 | 94                          | 89.6     |
| 0.3                    | 1.2 | 0    | 94                          | 89.6     |
| 0.3                    | 1.1 | 0    | 94                          | 89.6     |
| 0.3                    | 1   | 0    | 94                          | 89.7     |
| 0.3                    | 0.9 | 0    | 94.1                        | 89.7     |
| 0.2                    | 0.8 | -0.1 | 94.1                        | 89.8     |
| 0.1                    | 0.8 | -0.2 | 94.1                        | 89.8     |
| 0                      | 0.7 | -0.3 | 94.1                        | 89.8     |
| -0.1                   | 0.7 | -0.4 | 94.1                        | 89.9     |
| -0.2                   | 0.7 | -0.5 | 94.1                        | 89.9     |
| -0.3                   | 0.7 | -0.6 | 94.1                        | 90.0     |
| -0.3                   | 0.7 | -0.7 | 94                          | 90.0     |
| -0.3                   | 0.8 | -0.7 | 94                          | 90.0     |
| -0.3                   | 0.8 | -0.7 | 94                          | 90.1     |
| -0.3                   | 0.8 | -0.6 | 94                          | 90.1     |
| -0.2                   | 0.8 | -0.5 | 93.9                        | 90.2     |
| -0.2                   | 0.7 | -0.4 | 93.9                        | 90.2     |
| -0.1                   | 0.7 | -0.3 | 93.9                        | 90.2     |
| 0                      | 0.6 | -0.2 | 93.9                        | 90.3     |
| 0                      | 0.5 | -0.2 | 94                          | 90.3     |
| 0                      | 0.4 | -0.1 | 94                          | 90.4     |
| 0                      | 0.4 | -0.2 | 94                          | 90.4     |
| 0                      | 0.3 | -0.2 | 94                          | 90.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.1                   | 0.3  | -0.2 | 94                          | 90.5     |
| -0.2                   | 0.3  | -0.3 | 94                          | 90.5     |
| -0.3                   | 0.3  | -0.4 | 94                          | 90.6     |
| -0.3                   | 0.3  | -0.4 | 94                          | 90.6     |
| -0.4                   | 0.3  | -0.4 | 94                          | 90.6     |
| -0.5                   | 0.3  | -0.4 | 94                          | 90.7     |
| -0.5                   | 0.3  | -0.4 | 93.9                        | 90.7     |
| -0.5                   | 0.2  | -0.4 | 93.9                        | 90.8     |
| -0.5                   | 0.2  | -0.3 | 93.9                        | 90.8     |
| -0.4                   | 0.1  | -0.2 | 93.9                        | 90.8     |
| -0.3                   | 0    | -0.2 | 93.9                        | 90.9     |
| -0.2                   | 0    | -0.1 | 93.9                        | 90.9     |
| -0.1                   | -0.1 | -0.1 | 94                          | 91.0     |
| -0.1                   | -0.1 | 0    | 94                          | 91.0     |
| -0.1                   | -0.1 | -0.1 | 94                          | 91.0     |
| -0.1                   | -0.1 | -0.1 | 94                          | 91.1     |
| -0.2                   | 0    | -0.2 | 94                          | 91.1     |
| -0.3                   | 0    | -0.3 | 94                          | 91.2     |
| -0.4                   | 0.1  | -0.3 | 94                          | 91.2     |
| -0.5                   | 0.2  | -0.4 | 94                          | 91.2     |
| -0.5                   | 0.2  | -0.5 | 94                          | 91.3     |
| -0.6                   | 0.3  | -0.5 | 94                          | 91.3     |
| -0.7                   | 0.3  | -0.6 | 94                          | 91.4     |
| -0.7                   | 0.3  | -0.5 | 94                          | 91.4     |
| -0.7                   | 0.3  | -0.5 | 93.9                        | 91.4     |
| -0.7                   | 0.2  | -0.4 | 93.9                        | 91.5     |
| -0.6                   | 0.1  | -0.3 | 93.9                        | 91.5     |
| -0.6                   | 0.1  | -0.1 | 93.9                        | 91.6     |
| -0.5                   | 0    | 0    | 93.9                        | 91.6     |
| -0.4                   | -0.1 | 0    | 94                          | 91.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.4                   | -0.1 | 0.1  | 94                          | 91.7     |
| -0.3                   | -0.1 | 0    | 94                          | 91.7     |
| -0.3                   | 0    | -0.1 | 94                          | 91.8     |
| -0.3                   | 0    | -0.2 | 94.1                        | 91.8     |
| -0.2                   | 0.1  | -0.3 | 94.1                        | 91.8     |
| -0.2                   | 0.2  | -0.5 | 94.1                        | 91.9     |
| -0.2                   | 0.3  | -0.6 | 94                          | 91.9     |
| -0.2                   | 0.4  | -0.7 | 94                          | 92.0     |
| -0.2                   | 0.5  | -0.8 | 94                          | 92.0     |
| -0.1                   | 0.6  | -0.8 | 93.9                        | 92.0     |
| -0.1                   | 0.7  | -0.8 | 93.9                        | 92.1     |
| -0.1                   | 0.7  | -0.7 | 93.8                        | 92.1     |
| -0.1                   | 0.8  | -0.6 | 93.8                        | 92.2     |
| -0.1                   | 0.6  | -0.4 | 93.2                        | 92.2     |
| 0                      | 0.8  | -0.3 | 93.1                        | 92.2     |
| 0                      | 0.8  | -0.2 | 93.8                        | 92.3     |
| 0                      | 0.9  | -0.1 | 93.8                        | 92.3     |
| 0                      | 0.9  | 0    | 93.9                        | 92.4     |
| 0                      | 0.9  | 0    | 93.9                        | 92.4     |
| 0                      | 0.9  | 0    | 93.9                        | 92.4     |
| 0                      | 1    | -0.1 | 93.9                        | 92.5     |
| 0                      | 1    | -0.1 | 93.9                        | 92.5     |
| -0.1                   | 1    | -0.2 | 93.9                        | 92.6     |
| -0.1                   | 1    | -0.2 | 93.9                        | 92.6     |
| -0.1                   | 1    | -0.2 | 93.9                        | 92.6     |
| -0.2                   | 1    | -0.2 | 93.9                        | 92.7     |
| -0.2                   | 1    | -0.2 | 93.9                        | 92.7     |
| -0.2                   | 0.9  | -0.1 | 93.9                        | 92.8     |
| -0.2                   | 0.9  | -0.1 | 93.9                        | 92.8     |
| -0.2                   | 0.9  | 0    | 93.9                        | 92.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.2                   | 0   | 0    | 94                          | 92.9     |
| -0.2                   | 0.8 | 0    | 94                          | 92.9     |
| -0.2                   | 0.7 | 0.1  | 94                          | 93.0     |
| -0.2                   | 0.7 | 0    | 94                          | 93.0     |
| -0.2                   | 0.7 | 0    | 94                          | 93.0     |
| -0.2                   | 0.6 | 0    | 94                          | 93.1     |
| -0.2                   | 0.7 | -0.1 | 94.1                        | 93.1     |
| -0.1                   | 0.6 | -0.2 | 94.1                        | 93.2     |
| -0.1                   | 0.6 | -0.3 | 94.1                        | 93.2     |
| -0.1                   | 0.6 | -0.4 | 94.1                        | 93.2     |
| -0.1                   | 0.6 | -0.5 | 94                          | 93.3     |
| 0                      | 0.5 | -0.5 | 94                          | 93.3     |
| 0                      | 0.5 | -0.5 | 94                          | 93.4     |
| 0.1                    | 0.4 | -0.5 | 94                          | 93.4     |
| 0.2                    | 0.4 | -0.5 | 94                          | 93.4     |
| 0.2                    | 0.4 | -0.5 | 94                          | 93.5     |
| 0.3                    | 0.4 | -0.4 | 93.9                        | 93.5     |
| 0.3                    | 0.4 | -0.3 | 93.9                        | 93.6     |
| 0.3                    | 0.4 | -0.3 | 93.9                        | 93.6     |
| 0.3                    | 0.4 | -0.2 | 93.9                        | 93.6     |
| 0.3                    | 0.4 | -0.2 | 94                          | 93.7     |
| 0.2                    | 0.5 | -0.2 | 94                          | 93.7     |
| 0.2                    | 0.6 | -0.2 | 94                          | 93.8     |
| 0.1                    | 0.6 | -0.2 | 94                          | 93.8     |
| 0                      | 0.7 | -0.2 | 94                          | 93.8     |
| 0                      | 0.7 | -0.2 | 94                          | 93.9     |
| -0.1                   | 0.7 | -0.2 | 94                          | 93.9     |
| -0.1                   | 0.7 | -0.2 | 94                          | 94.0     |
| -0.2                   | 0.7 | -0.2 | 94                          | 94.0     |
| -0.2                   | 0.7 | -0.2 | 94                          | 94.0     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.2                   | 0.6  | -0.1 | 94                          | 94.1     |
| -0.1                   | 0.6  | -0.1 | 94                          | 94.1     |
| -0.1                   | 0.5  | -0.1 | 94                          | 94.2     |
| -0.1                   | 0.4  | -0.1 | 94                          | 94.2     |
| -0.1                   | 0.4  | -0.1 | 94                          | 94.2     |
| -0.1                   | 0.4  | -0.1 | 94                          | 94.3     |
| -0.1                   | 0.3  | -0.1 | 94                          | 94.3     |
| -0.1                   | 0.3  | -0.2 | 94                          | 94.4     |
| -0.2                   | 0.3  | -0.2 | 94.1                        | 94.4     |
| -0.2                   | 0.3  | -0.3 | 94.1                        | 94.4     |
| -0.2                   | 0.2  | -0.3 | 94                          | 94.5     |
| -0.2                   | 0.2  | -0.4 | 94                          | 94.5     |
| -0.2                   | 0.2  | -0.4 | 94                          | 94.6     |
| -0.1                   | 0.1  | -0.4 | 94                          | 94.6     |
| -0.1                   | 0    | -0.4 | 94                          | 94.6     |
| -0.1                   | 0    | -0.4 | 94                          | 94.7     |
| -0.1                   | -0.1 | -0.4 | 94                          | 94.7     |
| -0.1                   | -0.2 | -0.3 | 94                          | 94.8     |
| -0.2                   | -0.2 | -0.3 | 94                          | 94.8     |
| -0.2                   | -0.2 | -0.3 | 94                          | 94.8     |
| -0.3                   | -0.2 | -0.3 | 94                          | 94.9     |
| -0.3                   | -0.1 | -0.3 | 94                          | 94.9     |
| -0.4                   | 0    | -0.3 | 94                          | 95.0     |
| -0.5                   | 0.1  | -0.3 | 94                          | 95.0     |
| -0.6                   | 0.3  | -0.3 | 94                          | 95.0     |
| -0.6                   | 0.4  | -0.3 | 94                          | 95.1     |
| -0.7                   | 0.5  | -0.3 | 93.9                        | 95.1     |
| -0.7                   | 0.6  | -0.3 | 93.9                        | 95.2     |
| -0.7                   | 0.7  | -0.3 | 93.9                        | 95.2     |
| -0.7                   | 0.8  | -0.3 | 93.9                        | 95.2     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.7                   | 0.8 | -0.3 | 93.9                        | 95.3     |
| -0.7                   | 0.8 | -0.2 | 93.9                        | 95.3     |
| -0.7                   | 0.7 | -0.2 | 93.9                        | 95.4     |
| -0.7                   | 0.6 | -0.2 | 93.9                        | 95.4     |
| -0.6                   | 0.6 | -0.1 | 93.9                        | 95.4     |
| -0.6                   | 0.5 | -0.1 | 93.9                        | 95.5     |
| -0.6                   | 0.5 | -0.1 | 94                          | 95.5     |
| -0.6                   | 0.4 | -0.1 | 94                          | 95.6     |
| -0.6                   | 0.4 | -0.1 | 94                          | 95.6     |
| -0.6                   | 0.4 | -0.1 | 94                          | 95.6     |
| -0.5                   | 0.4 | -0.1 | 94                          | 95.7     |
| -0.5                   | 0.4 | -0.1 | 94                          | 95.7     |
| -0.4                   | 0.5 | -0.1 | 94                          | 95.8     |
| -0.3                   | 0.6 | -0.1 | 94                          | 95.8     |
| -0.3                   | 0.6 | -0.1 | 94                          | 95.8     |
| -0.2                   | 0.7 | -0.1 | 94                          | 95.9     |
| -0.1                   | 0.7 | -0.1 | 94                          | 95.9     |
| 0                      | 0.7 | -0.1 | 94                          | 96.0     |
| 0                      | 0.7 | -0.1 | 94                          | 96.0     |
| 0                      | 0.7 | -0.2 | 94                          | 96.0     |
| 0                      | 0.7 | -0.3 | 94                          | 96.1     |
| 0                      | 0.6 | -0.4 | 94                          | 96.1     |
| 0                      | 0.6 | -0.5 | 94                          | 96.2     |
| -0.1                   | 0.5 | -0.6 | 94                          | 96.2     |
| -0.2                   | 0.5 | -0.7 | 94                          | 96.2     |
| -0.3                   | 0.5 | -0.7 | 93.9                        | 96.3     |
| -0.4                   | 0.4 | -0.7 | 93.9                        | 96.3     |
| -0.4                   | 0.4 | -0.7 | 93.9                        | 96.4     |
| -0.4                   | 0.4 | -0.6 | 93.8                        | 96.4     |
| -0.4                   | 0.4 | -0.5 | 94                          | 96.4     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.4                   | 0.3 | -0.4 | 93.8                        | 96.5     |
| -0.3                   | 0.3 | -0.2 | 93.8                        | 96.5     |
| -0.3                   | 0.3 | 0    | 93.8                        | 96.6     |
| -0.2                   | 0.3 | 0.2  | 93.8                        | 96.6     |
| -0.1                   | 0.3 | 0.3  | 93.8                        | 96.6     |
| -0.1                   | 0.3 | 0.4  | 93.9                        | 96.7     |
| 0                      | 0.2 | 0.4  | 93.9                        | 96.7     |
| 0                      | 0.2 | 0.4  | 94                          | 96.8     |
| 0                      | 0.3 | 0.3  | 94                          | 96.8     |
| -0.1                   | 0.3 | 0.2  | 94                          | 96.8     |
| -0.1                   | 0.3 | 0    | 94.1                        | 96.9     |
| -0.2                   | 0.4 | -0.1 | 94.1                        | 96.9     |
| -0.3                   | 0.4 | -0.3 | 94.1                        | 97.0     |
| -0.3                   | 0.5 | -0.4 | 94                          | 97.0     |
| -0.4                   | 0.5 | -0.5 | 94                          | 97.0     |
| -0.4                   | 0.5 | -0.6 | 94                          | 97.1     |
| -0.3                   | 0.5 | -0.6 | 94                          | 97.1     |
| -0.3                   | 0.5 | -0.5 | 93.9                        | 97.2     |
| -0.2                   | 0.4 | -0.4 | 93.9                        | 97.2     |
| 0                      | 0.4 | -0.3 | 93.9                        | 97.2     |
| 0.1                    | 0.3 | -0.2 | 93.9                        | 97.3     |
| 0.2                    | 0.3 | -0.1 | 93.9                        | 97.3     |
| 0.3                    | 0.3 | 0    | 93.9                        | 97.4     |
| 0.4                    | 0.3 | 0.1  | 93.9                        | 97.4     |
| 0.4                    | 0.3 | 0.1  | 93.9                        | 97.4     |
| 0.4                    | 0.3 | 0.1  | 94                          | 97.5     |
| 0.3                    | 0.4 | 0.1  | 94                          | 97.5     |
| 0.3                    | 0.4 | 0.1  | 94                          | 97.6     |
| 0.2                    | 0.4 | 0    | 94                          | 97.6     |
| 0.1                    | 0.5 | 0    | 94                          | 97.6     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.1                    | 0.5 | -0.1 | 94                          | 97.7     |
| 0                      | 0.5 | -0.2 | 94                          | 97.7     |
| 0                      | 0.5 | -0.3 | 94                          | 97.8     |
| -0.1                   | 0.5 | -0.3 | 94                          | 97.8     |
| -0.1                   | 0.4 | -0.3 | 94                          | 97.8     |
| -0.1                   | 0.4 | -0.3 | 94                          | 97.9     |
| 0                      | 0.4 | -0.3 | 94                          | 97.9     |
| 0                      | 0.4 | -0.3 | 94                          | 98.0     |
| 0                      | 0.4 | -0.3 | 94                          | 98.0     |
| 0.1                    | 0.5 | -0.2 | 94                          | 98.0     |
| 0.1                    | 0.6 | -0.2 | 94                          | 98.1     |
| 0.1                    | 0.7 | -0.1 | 94                          | 98.1     |
| 0                      | 0.8 | -0.1 | 94                          | 98.2     |
| -0.1                   | 0.9 | -0.1 | 94                          | 98.2     |
| -0.2                   | 1   | -0.2 | 94                          | 98.2     |
| -0.3                   | 1   | -0.2 | 94                          | 98.3     |
| -0.4                   | 1.1 | -0.2 | 94                          | 98.3     |
| -0.4                   | 1.1 | -0.3 | 94                          | 98.4     |
| -0.5                   | 1   | -0.3 | 94                          | 98.4     |
| -0.5                   | 0.9 | -0.3 | 94                          | 98.4     |
| -0.5                   | 0.8 | -0.3 | 94                          | 98.5     |
| -0.5                   | 0.7 | -0.3 | 94                          | 98.5     |
| -0.5                   | 0.6 | -0.2 | 93.9                        | 98.6     |
| -0.4                   | 0.5 | -0.2 | 93.9                        | 98.6     |
| -0.3                   | 0.4 | -0.1 | 93.9                        | 98.6     |
| -0.3                   | 0.4 | -0.1 | 93.9                        | 98.7     |
| -0.2                   | 0.3 | -0.1 | 94                          | 98.7     |
| -0.2                   | 0.3 | -0.1 | 94                          | 98.8     |
| -0.2                   | 0.3 | -0.1 | 94                          | 98.8     |
| -0.3                   | 0.3 | -0.1 | 94                          | 98.8     |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.3                   | 0.3 | -0.1 | 94                          | 98.9     |
| -0.4                   | 0.3 | -0.1 | 94                          | 98.9     |
| -0.5                   | 0.3 | -0.1 | 94                          | 99.0     |
| -0.6                   | 0.4 | -0.1 | 94                          | 99.0     |
| -0.6                   | 0.4 | -0.1 | 94                          | 99.0     |
| -0.7                   | 0.4 | -0.1 | 94                          | 99.1     |
| -0.7                   | 0.4 | -0.1 | 94                          | 99.1     |
| -0.7                   | 0.4 | 0    | 94                          | 99.2     |
| -0.7                   | 0.4 | 0    | 94                          | 99.2     |
| -0.6                   | 0.3 | 0.1  | 94                          | 99.2     |
| -0.6                   | 0.3 | 0.1  | 94                          | 99.3     |
| -0.5                   | 0.3 | 0.1  | 94                          | 99.3     |
| -0.5                   | 0.3 | 0    | 94.1                        | 99.4     |
| -0.4                   | 0.2 | 0    | 94.1                        | 99.4     |
| -0.4                   | 0.2 | -0.1 | 94.1                        | 99.4     |
| -0.3                   | 0.2 | -0.2 | 94.1                        | 99.5     |
| -0.3                   | 0.1 | -0.3 | 94.1                        | 99.5     |
| -0.3                   | 0.1 | -0.4 | 94.1                        | 99.6     |
| -0.3                   | 0.1 | -0.4 | 94                          | 99.6     |
| -0.4                   | 0.1 | -0.4 | 94                          | 99.6     |
| -0.4                   | 0.1 | -0.4 | 94                          | 99.7     |
| -0.4                   | 0.1 | -0.4 | 94                          | 99.7     |
| -0.4                   | 0.1 | -0.4 | 94                          | 99.8     |
| -0.4                   | 0.1 | -0.3 | 94                          | 99.8     |
| -0.4                   | 0.1 | -0.3 | 93.9                        | 99.8     |
| -0.4                   | 0.1 | -0.3 | 93.9                        | 99.9     |
| -0.4                   | 0.1 | -0.2 | 93.9                        | 99.9     |
| -0.4                   | 0.1 | -0.2 | 93.9                        | 100.0    |
| -0.4                   | 0.1 | -0.2 | 93.9                        | 100.0    |
| -0.4                   | 0.1 | -0.2 | 93.9                        | 100.0    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.4                   | 0.1 | -0.2 | 93.9                        | 100.1    |
| -0.4                   | 0.2 | -0.3 | 93.9                        | 100.1    |
| -0.3                   | 0.2 | -0.3 | 93.9                        | 100.2    |
| -0.3                   | 0.2 | -0.3 | 93.9                        | 100.2    |
| -0.3                   | 0.2 | -0.3 | 93.9                        | 100.2    |
| -0.3                   | 0.2 | -0.3 | 93.9                        | 100.3    |
| -0.3                   | 0.2 | -0.2 | 93.9                        | 100.3    |
| -0.3                   | 0.2 | -0.2 | 93.9                        | 100.4    |
| -0.3                   | 0.2 | -0.1 | 93.9                        | 100.4    |
| -0.3                   | 0.1 | 0    | 93.9                        | 100.4    |
| -0.3                   | 0.1 | 0    | 93.9                        | 100.5    |
| -0.3                   | 0.1 | 0.1  | 93.9                        | 100.5    |
| -0.3                   | 0.1 | 0.1  | 93.9                        | 100.6    |
| -0.4                   | 0   | 0.1  | 93.9                        | 100.6    |
| -0.4                   | 0.1 | 0.1  | 93.9                        | 100.6    |
| -0.3                   | 0.1 | 0.1  | 94                          | 100.7    |
| -0.3                   | 0.1 | 0    | 94                          | 100.7    |
| -0.3                   | 0.2 | 0    | 94                          | 100.8    |
| -0.2                   | 0.3 | -0.1 | 94                          | 100.8    |
| -0.1                   | 0.3 | -0.1 | 94                          | 100.8    |
| -0.1                   | 0.4 | -0.1 | 94                          | 100.9    |
| 0                      | 0.5 | -0.1 | 93.9                        | 100.9    |
| 0                      | 0.5 | -0.1 | 93.9                        | 101.0    |
| 0.1                    | 0.5 | 0    | 94                          | 101.0    |
| 0.1                    | 0.5 | 0    | 94                          | 101.0    |
| 0.1                    | 0.5 | 0    | 94                          | 101.1    |
| 0.1                    | 0.4 | 0    | 94                          | 101.1    |
| 0.1                    | 0.4 | 0    | 94                          | 101.2    |
| 0                      | 0.4 | -0.1 | 94                          | 101.2    |
| 0                      | 0.4 | -0.1 | 94                          | 101.2    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.1                   | 0.5 | -0.2 | 94                          | 101.3    |
| -0.1                   | 0.5 | -0.2 | 94                          | 101.3    |
| -0.2                   | 0.6 | -0.3 | 94                          | 101.4    |
| -0.3                   | 0.7 | -0.3 | 93.9                        | 101.4    |
| -0.3                   | 0.8 | -0.3 | 94                          | 101.4    |
| -0.3                   | 0.9 | -0.3 | 93.9                        | 101.5    |
| -0.3                   | 1   | -0.3 | 93.9                        | 101.5    |
| -0.3                   | 1   | -0.2 | 93.9                        | 101.6    |
| -0.3                   | 1.1 | -0.1 | 93.9                        | 101.6    |
| -0.2                   | 1.1 | 0    | 93.9                        | 101.6    |
| -0.2                   | 1.1 | 0.1  | 93.9                        | 101.7    |
| -0.1                   | 1.1 | 0.2  | 93.9                        | 101.7    |
| -0.1                   | 1.1 | 0.3  | 94                          | 101.8    |
| 0                      | 1   | 0.3  | 94                          | 101.8    |
| 0                      | 1   | 0.3  | 94                          | 101.8    |
| 0                      | 0.9 | 0.2  | 94                          | 101.9    |
| 0                      | 0.9 | 0.1  | 94.1                        | 101.9    |
| 0                      | 0.9 | 0    | 94.1                        | 102.0    |
| -0.1                   | 0.8 | -0.1 | 94.1                        | 102.0    |
| -0.1                   | 0.8 | -0.2 | 94.1                        | 102.0    |
| -0.1                   | 0.8 | -0.3 | 94.1                        | 102.1    |
| -0.2                   | 0.7 | -0.4 | 94                          | 102.1    |
| -0.1                   | 0.7 | -0.5 | 94                          | 102.2    |
| -0.1                   | 0.6 | -0.5 | 94                          | 102.2    |
| -0.1                   | 0.6 | -0.4 | 94                          | 102.2    |
| 0                      | 0.5 | -0.4 | 93.9                        | 102.3    |
| 0.1                    | 0.4 | -0.3 | 93.9                        | 102.3    |
| 0.1                    | 0.3 | -0.2 | 93.9                        | 102.4    |
| 0.2                    | 0.2 | -0.1 | 93.9                        | 102.4    |
| 0.2                    | 0.2 | 0    | 93.9                        | 102.4    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| 0.2                    | 0.1  | 0.1  | 93.9                        | 102.5    |
| 0.1                    | 0.1  | 0.2  | 94                          | 102.5    |
| 0                      | 0    | 0.2  | 94                          | 102.6    |
| -0.1                   | 0    | 0.2  | 94                          | 102.6    |
| -0.2                   | 0    | 0.2  | 94                          | 102.6    |
| -0.4                   | 0.1  | 0.1  | 94                          | 102.7    |
| -0.5                   | 0    | 0    | 94                          | 102.7    |
| -0.6                   | 0.1  | 0    | 94                          | 102.8    |
| -0.7                   | 0.1  | -0.1 | 94.1                        | 102.8    |
| -0.7                   | 0.1  | -0.2 | 94                          | 102.8    |
| -0.7                   | 0.2  | -0.2 | 94                          | 102.9    |
| -0.7                   | 0.2  | -0.3 | 94                          | 102.9    |
| -0.7                   | 0.2  | -0.3 | 94                          | 103.0    |
| -0.7                   | 0.2  | -0.2 | 94                          | 103.0    |
| -0.6                   | 0.2  | -0.2 | 94                          | 103.0    |
| -0.6                   | 0.2  | -0.1 | 94                          | 103.1    |
| -0.6                   | 0.1  | -0.1 | 94                          | 103.1    |
| -0.5                   | 0.1  | 0    | 94                          | 103.2    |
| -0.5                   | 0    | 0    | 94                          | 103.2    |
| -0.5                   | 0    | 0    | 94                          | 103.2    |
| -0.5                   | -0.1 | 0    | 94                          | 103.3    |
| -0.6                   | -0.1 | 0    | 94                          | 103.3    |
| -0.6                   | -0.1 | 0    | 94                          | 103.4    |
| -0.6                   | -0.2 | 0    | 94                          | 103.4    |
| -0.6                   | -0.2 | -0.1 | 94                          | 103.4    |
| -0.5                   | -0.2 | -0.1 | 94                          | 103.5    |
| -0.5                   | -0.2 | -0.2 | 94                          | 103.5    |
| -0.4                   | -0.2 | -0.2 | 94                          | 103.6    |
| -0.3                   | -0.2 | -0.2 | 94                          | 103.6    |
| -0.2                   | -0.2 | -0.2 | 94                          | 103.6    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.2                   | -0.2 | -0.2 | 93.9                        | 103.7    |
| -0.1                   | -0.1 | -0.2 | 94                          | 103.7    |
| -0.1                   | 0    | -0.2 | 94                          | 103.8    |
| -0.1                   | 0.1  | -0.3 | 94                          | 103.8    |
| -0.1                   | 0.1  | -0.3 | 94                          | 103.8    |
| -0.1                   | 0.2  | -0.3 | 93.9                        | 103.9    |
| -0.2                   | 0.3  | -0.3 | 93.9                        | 103.9    |
| -0.2                   | 0.4  | -0.3 | 93.9                        | 104.0    |
| -0.3                   | 0.4  | -0.3 | 93.9                        | 104.0    |
| -0.4                   | 0.4  | -0.3 | 93.9                        | 104.0    |
| -0.4                   | 0.4  | -0.3 | 93.9                        | 104.1    |
| -0.5                   | 0.4  | -0.2 | 93.9                        | 104.1    |
| -0.5                   | 0.4  | -0.1 | 93.8                        | 104.2    |
| -0.6                   | 0.4  | 0    | 93.8                        | 104.2    |
| -0.6                   | 0.3  | 0.1  | 93.8                        | 104.2    |
| -0.6                   | 0.3  | 0.1  | 93.9                        | 104.3    |
| -0.6                   | 0.3  | 0.2  | 93.9                        | 104.3    |
| -0.6                   | 0.3  | 0.3  | 93.9                        | 104.4    |
| -0.6                   | 0.3  | 0.3  | 93.9                        | 104.4    |
| -0.5                   | 0.3  | 0.3  | 93.9                        | 104.4    |
| -0.5                   | 0.4  | 0.3  | 94                          | 104.5    |
| -0.5                   | 0.5  | 0.2  | 94                          | 104.5    |
| -0.5                   | 0.5  | 0.2  | 94                          | 104.6    |
| -0.5                   | 0.6  | 0.1  | 94                          | 104.6    |
| -0.5                   | 0.6  | 0    | 94                          | 104.6    |
| -0.5                   | 0.7  | 0    | 94                          | 104.7    |
| -0.4                   | 0.7  | -0.1 | 94                          | 104.7    |
| -0.4                   | 0.7  | -0.1 | 94                          | 104.8    |
| -0.4                   | 0.7  | -0.2 | 94                          | 104.8    |
| -0.4                   | 0.7  | -0.2 | 94                          | 104.8    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.4                   | 0.6 | -0.2 | 94                          | 104.9    |
| -0.3                   | 0.6 | -0.2 | 94                          | 104.9    |
| -0.3                   | 0.5 | -0.3 | 94                          | 105.0    |
| -0.3                   | 0.5 | -0.3 | 93.9                        | 105.0    |
| -0.2                   | 0.4 | -0.2 | 93.9                        | 105.0    |
| -0.2                   | 0.4 | -0.2 | 93.9                        | 105.1    |
| -0.1                   | 0.4 | -0.2 | 93.9                        | 105.1    |
| -0.1                   | 0.4 | -0.1 | 93.9                        | 105.2    |
| 0                      | 0.5 | -0.1 | 93.9                        | 105.2    |
| 0                      | 0.5 | 0    | 93.9                        | 105.2    |
| 0                      | 0.5 | 0    | 93.9                        | 105.3    |
| 0.1                    | 0.6 | 0.1  | 93.9                        | 105.3    |
| 0.1                    | 0.6 | 0.1  | 93.9                        | 105.4    |
| 0.1                    | 0.6 | 0.1  | 93.9                        | 105.4    |
| 0.1                    | 0.6 | 0.2  | 93.9                        | 105.4    |
| 0.1                    | 0.5 | 0.2  | 94                          | 105.5    |
| 0.1                    | 0.5 | 0.2  | 94                          | 105.5    |
| 0.1                    | 0.4 | 0.2  | 94                          | 105.6    |
| 0                      | 0.4 | 0.1  | 94                          | 105.6    |
| 0                      | 0.3 | 0.1  | 94                          | 105.6    |
| 0                      | 0.3 | 0.1  | 94                          | 105.7    |
| 0                      | 0.3 | 0.1  | 94                          | 105.7    |
| 0                      | 0.3 | 0    | 94                          | 105.8    |
| -0.1                   | 0.3 | 0    | 94                          | 105.8    |
| -0.1                   | 0.4 | 0    | 94                          | 105.8    |
| -0.1                   | 0.4 | -0.1 | 94                          | 105.9    |
| -0.1                   | 0.5 | -0.1 | 94                          | 105.9    |
| -0.1                   | 0.5 | -0.1 | 94                          | 106.0    |
| -0.1                   | 0.6 | -0.1 | 94                          | 106.0    |
| -0.1                   | 0.6 | -0.1 | 94                          | 106.0    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.1                   | 0.6  | -0.1 | 94                          | 106.1    |
| -0.1                   | 0.6  | -0.1 | 94                          | 106.1    |
| 0                      | 0.5  | -0.1 | 93.9                        | 106.2    |
| 0                      | 0.5  | 0    | 94                          | 106.2    |
| 0                      | 0.4  | 0    | 94                          | 106.2    |
| 0.1                    | 0.3  | 0    | 94                          | 106.3    |
| 0.1                    | 0.2  | 0    | 94                          | 106.3    |
| 0.1                    | 0.1  | 0    | 94                          | 106.4    |
| 0                      | 0.1  | 0    | 94                          | 106.4    |
| 0                      | 0    | -0.1 | 94                          | 106.4    |
| -0.1                   | -0.1 | -0.1 | 94                          | 106.5    |
| -0.2                   | -0.1 | -0.2 | 94                          | 106.5    |
| -0.2                   | -0.1 | -0.2 | 94                          | 106.6    |
| -0.3                   | -0.1 | -0.2 | 94                          | 106.6    |
| -0.4                   | -0.1 | -0.2 | 93.9                        | 106.6    |
| -0.4                   | -0.1 | -0.2 | 93.9                        | 106.7    |
| -0.5                   | -0.1 | -0.1 | 93.9                        | 106.7    |
| -0.5                   | -0.1 | 0    | 93.9                        | 106.8    |
| -0.5                   | -0.1 | 0    | 93.9                        | 106.8    |
| -0.5                   | 0    | 0.1  | 93.9                        | 106.8    |
| -0.5                   | 0    | 0.2  | 93.9                        | 106.9    |
| -0.5                   | 0    | 0.2  | 94                          | 106.9    |
| -0.5                   | 0.1  | 0.2  | 94                          | 107.0    |
| -0.5                   | 0.2  | 0.2  | 94                          | 107.0    |
| -0.5                   | 0.2  | 0.2  | 94                          | 107.0    |
| -0.5                   | 0.3  | 0.1  | 94                          | 107.1    |
| -0.5                   | 0.3  | 0.1  | 94                          | 107.1    |
| -0.5                   | 0.3  | 0    | 94                          | 107.2    |
| -0.5                   | 0.3  | -0.1 | 94                          | 107.2    |
| -0.5                   | 0.3  | -0.1 | 94                          | 107.2    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 0.3  | -0.1 | 94                          | 107.3    |
| -0.5                   | 0.3  | -0.1 | 94                          | 107.3    |
| -0.4                   | 0.3  | -0.1 | 94                          | 107.4    |
| -0.4                   | 0.3  | -0.1 | 94                          | 107.4    |
| -0.3                   | 0.3  | 0    | 94                          | 107.4    |
| -0.3                   | 0.3  | 0    | 94                          | 107.5    |
| -0.3                   | 0.3  | 0    | 94                          | 107.5    |
| -0.3                   | 0.4  | 0    | 94                          | 107.6    |
| -0.3                   | 0.4  | 0    | 94                          | 107.6    |
| -0.3                   | 0.4  | 0    | 94                          | 107.6    |
| -0.4                   | 0.4  | -0.1 | 94                          | 107.7    |
| -0.5                   | 0.5  | -0.1 | 94                          | 107.7    |
| -0.5                   | 0.5  | -0.1 | 94                          | 107.8    |
| -0.6                   | 0.6  | -0.2 | 94                          | 107.8    |
| -0.6                   | 0.6  | -0.2 | 94                          | 107.8    |
| -0.7                   | 0.6  | -0.2 | 94                          | 107.9    |
| -0.7                   | 0.6  | -0.2 | 94                          | 107.9    |
| -0.6                   | 0.6  | -0.2 | 94                          | 108.0    |
| -0.6                   | 0.6  | -0.2 | 93.9                        | 108.0    |
| -0.6                   | 0.5  | -0.1 | 93.9                        | 108.0    |
| -0.5                   | 0.4  | -0.1 | 93.9                        | 108.1    |
| -0.5                   | 0.3  | -0.1 | 93.9                        | 108.1    |
| -0.5                   | 0.2  | 0    | 93.9                        | 108.2    |
| -0.5                   | 0.1  | 0    | 93.9                        | 108.2    |
| -0.5                   | 0    | 0    | 93.9                        | 108.2    |
| -0.5                   | -0.1 | 0    | 93.9                        | 108.3    |
| -0.5                   | -0.1 | 0    | 93.9                        | 108.3    |
| -0.5                   | -0.2 | 0    | 93.9                        | 108.4    |
| -0.6                   | -0.2 | 0    | 93.9                        | 108.4    |
| -0.6                   | -0.1 | 0    | 93.9                        | 108.4    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.6                   | -0.1 | 0    | 93.9                        | 108.5    |
| -0.6                   | 0    | 0    | 93.9                        | 108.5    |
| -0.5                   | 0    | 0    | 93.9                        | 108.6    |
| -0.5                   | 0.1  | 0    | 93.9                        | 108.6    |
| -0.4                   | 0.1  | 0    | 93.9                        | 108.6    |
| -0.3                   | 0.1  | 0    | 93.9                        | 108.7    |
| -0.2                   | 0.1  | 0.1  | 93.9                        | 108.7    |
| -0.1                   | 0.1  | 0.1  | 93.9                        | 108.8    |
| -0.1                   | 0.1  | 0.2  | 93.9                        | 108.8    |
| 0                      | 0.1  | 0.2  | 93.9                        | 108.8    |
| 0                      | 0.1  | 0.2  | 94                          | 108.9    |
| 0                      | 0.1  | 0.2  | 94                          | 108.9    |
| 0                      | 0.1  | 0.1  | 94                          | 109.0    |
| -0.1                   | 0.2  | 0.1  | 94                          | 109.0    |
| -0.1                   | 0.2  | 0    | 94                          | 109.0    |
| -0.2                   | 0.2  | -0.1 | 94                          | 109.1    |
| -0.2                   | 0.2  | -0.1 | 94                          | 109.1    |
| -0.3                   | 0.2  | -0.2 | 94                          | 109.2    |
| -0.3                   | 0.2  | -0.2 | 94                          | 109.2    |
| -0.3                   | 0.2  | -0.2 | 93.9                        | 109.2    |
| -0.3                   | 0.2  | -0.1 | 93.9                        | 109.3    |
| -0.3                   | 0.2  | -0.1 | 93.9                        | 109.3    |
| -0.3                   | 0.2  | 0    | 93.9                        | 109.4    |
| -0.2                   | 0.1  | 0.1  | 93.9                        | 109.4    |
| -0.1                   | 0.1  | 0.2  | 93.9                        | 109.4    |
| 0                      | 0.1  | 0.3  | 93.9                        | 109.5    |
| 0.1                    | 0.2  | 0.4  | 94                          | 109.5    |
| 0.1                    | 0.2  | 0.4  | 94                          | 109.6    |
| 0.2                    | 0.2  | 0.4  | 94                          | 109.6    |
| 0.2                    | 0.3  | 0.3  | 94                          | 109.6    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| 0.2                    | 0.3 | 0.2  | 94.1                        | 109.7    |
| 0.2                    | 0.4 | 0.1  | 94.1                        | 109.7    |
| 0.2                    | 0.4 | -0.1 | 94.1                        | 109.8    |
| 0.1                    | 0.4 | -0.2 | 94.1                        | 109.8    |
| 0                      | 0.4 | -0.4 | 94                          | 109.8    |
| -0.1                   | 0.4 | -0.5 | 94                          | 109.9    |
| -0.1                   | 0.4 | -0.5 | 94                          | 109.9    |
| -0.1                   | 0.3 | -0.6 | 93.9                        | 110.0    |
| -0.1                   | 0.3 | -0.5 | 93.9                        | 110.0    |
| -0.1                   | 0.3 | -0.4 | 93.9                        | 110.0    |
| -0.1                   | 0.3 | -0.4 | 93.9                        | 110.1    |
| -0.1                   | 0.3 | -0.2 | 93.8                        | 110.1    |
| 0                      | 0.3 | -0.1 | 93.8                        | 110.2    |
| 0                      | 0.4 | 0    | 93.8                        | 110.2    |
| 0                      | 0.4 | 0.1  | 93.8                        | 110.2    |
| 0                      | 0.5 | 0.3  | 93.9                        | 110.3    |
| 0                      | 0.5 | 0.3  | 93.9                        | 110.3    |
| 0                      | 0.5 | 0.4  | 93.9                        | 110.4    |
| -0.1                   | 0.6 | 0.4  | 93.9                        | 110.4    |
| -0.1                   | 0.6 | 0.4  | 94                          | 110.4    |
| -0.2                   | 0.6 | 0.4  | 94                          | 110.5    |
| -0.3                   | 0.6 | 0.4  | 94                          | 110.5    |
| -0.3                   | 0.6 | 0.3  | 94                          | 110.6    |
| -0.4                   | 0.6 | 0.3  | 94                          | 110.6    |
| -0.4                   | 0.6 | 0.2  | 94                          | 110.6    |
| -0.5                   | 0.6 | 0.2  | 94.1                        | 110.7    |
| -0.5                   | 0.6 | 0.1  | 94.1                        | 110.7    |
| -0.5                   | 0.6 | 0.1  | 94                          | 110.8    |
| -0.5                   | 0.5 | 0    | 94.1                        | 110.8    |
| -0.5                   | 0.5 | 0    | 94.1                        | 110.8    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 0.5  | 0    | 94                          | 110.9    |
| -0.5                   | 0.5  | 0    | 94.1                        | 110.9    |
| -0.5                   | 0.5  | -0.1 | 94.1                        | 111.0    |
| -0.5                   | 0.4  | -0.1 | 94                          | 111.0    |
| -0.5                   | 0.4  | 0    | 94                          | 111.0    |
| -0.4                   | 0.3  | 0    | 94                          | 111.1    |
| -0.4                   | 0.3  | 0    | 94                          | 111.1    |
| -0.4                   | 0.2  | 0    | 94                          | 111.2    |
| -0.4                   | 0.2  | 0    | 94                          | 111.2    |
| -0.3                   | 0.1  | 0    | 94                          | 111.2    |
| -0.3                   | 0    | 0    | 94                          | 111.3    |
| -0.3                   | 0    | 0    | 94                          | 111.3    |
| -0.3                   | -0.1 | 0    | 94                          | 111.4    |
| -0.3                   | -0.1 | -0.1 | 94                          | 111.4    |
| -0.3                   | -0.1 | -0.1 | 94                          | 111.4    |
| -0.3                   | -0.1 | -0.2 | 94                          | 111.5    |
| -0.3                   | -0.1 | -0.2 | 94                          | 111.5    |
| -0.3                   | -0.1 | -0.3 | 94                          | 111.6    |
| -0.4                   | -0.1 | -0.3 | 94                          | 111.6    |
| -0.4                   | 0    | -0.3 | 94                          | 111.6    |
| -0.4                   | 0    | -0.3 | 93.9                        | 111.7    |
| -0.5                   | 0.1  | -0.3 | 93.9                        | 111.7    |
| -0.5                   | 0.1  | -0.3 | 93.9                        | 111.8    |
| -0.5                   | 0.2  | -0.2 | 93.9                        | 111.8    |
| -0.5                   | 0.2  | -0.1 | 93.9                        | 111.8    |
| -0.5                   | 0.2  | 0    | 93.9                        | 111.9    |
| -0.5                   | 0.1  | 0    | 93.9                        | 111.9    |
| -0.5                   | 0.1  | 0.2  | 93.9                        | 112.0    |
| -0.5                   | 0.1  | 0.2  | 93.9                        | 112.0    |
| -0.5                   | 0    | 0.3  | 93.9                        | 112.0    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | 0    | 0.3  | 93.9                        | 112.1    |
| -0.5                   | 0    | 0.3  | 93.9                        | 112.1    |
| -0.5                   | -0.1 | 0.3  | 94                          | 112.2    |
| -0.5                   | -0.1 | 0.3  | 94                          | 112.2    |
| -0.5                   | -0.1 | 0.2  | 94                          | 112.2    |
| -0.5                   | -0.1 | 0.2  | 94                          | 112.3    |
| -0.5                   | -0.1 | 0.1  | 94                          | 112.3    |
| -0.5                   | -0.1 | 0.1  | 94                          | 112.4    |
| -0.4                   | -0.2 | 0    | 94                          | 112.4    |
| -0.4                   | -0.2 | -0.1 | 94                          | 112.4    |
| -0.4                   | -0.3 | -0.1 | 94                          | 112.5    |
| -0.3                   | -0.4 | -0.1 | 94                          | 112.5    |
| -0.3                   | -0.4 | -0.1 | 94                          | 112.6    |
| -0.3                   | -0.5 | -0.1 | 94                          | 112.6    |
| -0.3                   | -0.5 | -0.1 | 94                          | 112.6    |
| -0.2                   | -0.5 | -0.1 | 93.9                        | 112.7    |
| -0.2                   | -0.5 | -0.1 | 93.9                        | 112.7    |
| -0.3                   | -0.4 | 0    | 93.9                        | 112.8    |
| -0.3                   | -0.3 | 0    | 93.9                        | 112.8    |
| -0.3                   | -0.2 | 0    | 93.9                        | 112.8    |
| -0.3                   | -0.1 | 0    | 93.9                        | 112.9    |
| -0.3                   | 0    | 0    | 93.9                        | 112.9    |
| -0.4                   | 0.1  | 0    | 93.9                        | 113.0    |
| -0.4                   | 0.2  | 0    | 93.9                        | 113.0    |
| -0.4                   | 0.3  | 0    | 93.9                        | 113.0    |
| -0.3                   | 0.4  | 0    | 93.9                        | 113.1    |
| -0.3                   | 0.4  | 0    | 93.9                        | 113.1    |
| -0.3                   | 0.4  | 0    | 93.9                        | 113.2    |
| -0.2                   | 0.5  | 0    | 93.9                        | 113.2    |
| -0.2                   | 0.5  | 0.1  | 93.9                        | 113.2    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.2                   | 0.5 | 0.1  | 93.9                        | 113.3    |
| -0.2                   | 0.5 | 0.2  | 93.9                        | 113.3    |
| -0.1                   | 0.5 | 0.2  | 93.9                        | 113.4    |
| -0.1                   | 0.6 | 0.2  | 93.9                        | 113.4    |
| -0.2                   | 0.6 | 0.2  | 94                          | 113.4    |
| -0.2                   | 0.6 | 0.2  | 94                          | 113.5    |
| -0.2                   | 0.7 | 0.2  | 94                          | 113.5    |
| -0.2                   | 0.7 | 0.1  | 94                          | 113.6    |
| -0.2                   | 0.7 | 0    | 94                          | 113.6    |
| -0.2                   | 0.8 | 0    | 94                          | 113.6    |
| -0.1                   | 0.8 | 0    | 94                          | 113.7    |
| -0.1                   | 0.8 | 0    | 93.9                        | 113.7    |
| 0                      | 0.8 | 0    | 94                          | 113.8    |
| 0.1                    | 0.8 | 0    | 94                          | 113.8    |
| 0.1                    | 0.7 | 0.1  | 93.9                        | 113.8    |
| 0.2                    | 0.7 | 0.1  | 93.9                        | 113.9    |
| 0.2                    | 0.7 | 0.2  | 94                          | 113.9    |
| 0.3                    | 0.6 | 0.2  | 94                          | 114.0    |
| 0.3                    | 0.6 | 0.2  | 94                          | 114.0    |
| 0.2                    | 0.5 | 0.1  | 94                          | 114.0    |
| 0.1                    | 0.4 | 0.1  | 94                          | 114.1    |
| 0.1                    | 0.4 | 0    | 94                          | 114.1    |
| 0                      | 0.3 | -0.1 | 94                          | 114.2    |
| -0.1                   | 0.3 | -0.1 | 94                          | 114.2    |
| -0.2                   | 0.2 | -0.2 | 94                          | 114.2    |
| -0.3                   | 0.2 | -0.2 | 94                          | 114.3    |
| -0.3                   | 0.2 | -0.1 | 93.9                        | 114.3    |
| -0.3                   | 0.2 | -0.1 | 93.9                        | 114.4    |
| -0.3                   | 0.2 | 0    | 93.9                        | 114.4    |
| -0.3                   | 0.1 | 0.1  | 93.9                        | 114.4    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.3                   | 0.1  | 0.2  | 93.9                        | 114.5    |
| -0.3                   | 0.2  | 0.3  | 93.9                        | 114.5    |
| -0.3                   | 0.2  | 0.3  | 94                          | 114.6    |
| -0.3                   | 0.2  | 0.3  | 94                          | 114.6    |
| -0.3                   | 0.2  | 0.3  | 94                          | 114.6    |
| -0.3                   | 0.2  | 0.3  | 94                          | 114.7    |
| -0.3                   | 0.2  | 0.2  | 94                          | 114.7    |
| -0.3                   | 0.2  | 0.1  | 94.1                        | 114.8    |
| -0.4                   | 0.2  | 0    | 94.1                        | 114.8    |
| -0.4                   | 0.2  | -0.1 | 94.1                        | 114.8    |
| -0.4                   | 0.1  | -0.1 | 94.1                        | 114.9    |
| -0.5                   | 0.1  | -0.2 | 94                          | 114.9    |
| -0.5                   | 0.1  | -0.2 | 94                          | 115.0    |
| -0.4                   | 0    | -0.2 | 94                          | 115.0    |
| -0.4                   | -0.1 | -0.1 | 94                          | 115.0    |
| -0.4                   | -0.1 | -0.1 | 94                          | 115.1    |
| -0.3                   | -0.2 | 0    | 94                          | 115.1    |
| -0.2                   | -0.2 | 0.1  | 94                          | 115.2    |
| -0.2                   | -0.3 | 0.2  | 94                          | 115.2    |
| -0.1                   | -0.3 | 0.2  | 94                          | 115.2    |
| 0                      | -0.3 | 0.2  | 94                          | 115.3    |
| 0                      | -0.2 | 0.2  | 94                          | 115.3    |
| 0                      | -0.2 | 0.1  | 94                          | 115.4    |
| -0.1                   | -0.2 | 0.1  | 94                          | 115.4    |
| -0.2                   | -0.1 | 0    | 94                          | 115.4    |
| -0.2                   | -0.1 | -0.1 | 94                          | 115.5    |
| -0.3                   | -0.1 | -0.1 | 94                          | 115.5    |
| -0.4                   | 0    | -0.2 | 94                          | 115.6    |
| -0.5                   | 0    | -0.2 | 94                          | 115.6    |
| -0.5                   | -0.1 | -0.2 | 94                          | 115.6    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.5                   | -0.1 | -0.1 | 94                          | 115.7    |
| -0.5                   | -0.1 | -0.1 | 93.9                        | 115.7    |
| -0.5                   | -0.2 | 0    | 93.9                        | 115.8    |
| -0.5                   | -0.2 | 0    | 93.9                        | 115.8    |
| -0.5                   | -0.3 | 0.1  | 94                          | 115.8    |
| -0.4                   | -0.3 | 0.1  | 94                          | 115.9    |
| -0.4                   | -0.3 | 0.1  | 94                          | 115.9    |
| -0.4                   | -0.3 | 0.1  | 94                          | 116.0    |
| -0.4                   | -0.3 | 0.1  | 94                          | 116.0    |
| -0.4                   | -0.2 | 0    | 94                          | 116.0    |
| -0.4                   | -0.2 | 0    | 94                          | 116.1    |
| -0.5                   | -0.1 | 0    | 94                          | 116.1    |
| -0.5                   | -0.1 | 0    | 94                          | 116.2    |
| -0.6                   | 0    | -0.1 | 94                          | 116.2    |
| -0.6                   | 0    | -0.1 | 94                          | 116.2    |
| -0.7                   | 0    | -0.1 | 93.9                        | 116.3    |
| -0.7                   | 0    | 0    | 93.9                        | 116.3    |
| -0.7                   | 0    | 0    | 93.9                        | 116.4    |
| -0.7                   | 0    | 0    | 93.9                        | 116.4    |
| -0.7                   | 0    | 0.1  | 93.9                        | 116.4    |
| -0.7                   | 0.1  | 0.1  | 93.9                        | 116.5    |
| -0.6                   | 0.1  | 0.1  | 93.9                        | 116.5    |
| -0.6                   | 0.1  | 0.2  | 93.9                        | 116.6    |
| -0.5                   | 0.2  | 0.1  | 93.9                        | 116.6    |
| -0.5                   | 0.3  | 0.1  | 93.9                        | 116.6    |
| -0.5                   | 0.3  | 0.1  | 94                          | 116.7    |
| -0.4                   | 0.4  | 0    | 94                          | 116.7    |
| -0.4                   | 0.4  | 0    | 94                          | 116.8    |
| -0.4                   | 0.4  | 0    | 94                          | 116.8    |
| -0.4                   | 0.4  | -0.1 | 93.9                        | 116.8    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.4                   | 0.3 | -0.1 | 93.9                        | 116.9    |
| -0.4                   | 0.3 | -0.1 | 93.9                        | 116.9    |
| -0.4                   | 0.2 | 0    | 93.9                        | 117.0    |
| -0.4                   | 0.2 | 0    | 93.9                        | 117.0    |
| -0.4                   | 0.1 | 0.1  | 93.9                        | 117.0    |
| -0.4                   | 0.1 | 0.2  | 93.9                        | 117.1    |
| -0.3                   | 0   | 0.3  | 93.9                        | 117.1    |
| -0.3                   | 0   | 0.3  | 93.9                        | 117.2    |
| -0.3                   | 0   | 0.4  | 94                          | 117.2    |
| -0.2                   | 0   | 0.4  | 94                          | 117.2    |
| -0.2                   | 0.1 | 0.4  | 94                          | 117.3    |
| -0.1                   | 0.1 | 0.3  | 94                          | 117.3    |
| 0                      | 0.2 | 0.3  | 94                          | 117.4    |
| 0                      | 0.2 | 0.2  | 94                          | 117.4    |
| 0.1                    | 0.3 | 0.1  | 94                          | 117.4    |
| 0.1                    | 0.3 | 0    | 94.1                        | 117.5    |
| 0.1                    | 0.4 | -0.1 | 94.1                        | 117.5    |
| 0.1                    | 0.4 | -0.2 | 94                          | 117.6    |
| 0.1                    | 0.4 | -0.2 | 94                          | 117.6    |
| 0.1                    | 0.4 | -0.2 | 94                          | 117.6    |
| 0.1                    | 0.4 | -0.3 | 94                          | 117.7    |
| 0                      | 0.3 | -0.3 | 94                          | 117.7    |
| 0                      | 0.3 | -0.2 | 93.9                        | 117.8    |
| 0                      | 0.3 | -0.2 | 93.9                        | 117.8    |
| -0.1                   | 0.2 | -0.2 | 93.9                        | 117.8    |
| -0.1                   | 0.2 | -0.1 | 93.9                        | 117.9    |
| -0.2                   | 0.2 | -0.1 | 93.9                        | 117.9    |
| -0.2                   | 0.1 | -0.1 | 93.9                        | 118.0    |
| -0.2                   | 0.1 | 0    | 93.9                        | 118.0    |
| -0.2                   | 0.1 | 0    | 93.9                        | 118.0    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |      |      | Water Surface Elevation (m) | Time (s) |
|------------------------|------|------|-----------------------------|----------|
| u                      | v    | w    |                             |          |
| -0.2                   | 0    | 0.1  | 93.9                        | 118.1    |
| -0.1                   | 0    | 0.1  | 93.9                        | 118.1    |
| -0.1                   | -0.1 | 0.2  | 93.9                        | 118.2    |
| -0.1                   | -0.1 | 0.3  | 93.9                        | 118.2    |
| 0                      | -0.1 | 0.3  | 93.9                        | 118.2    |
| 0                      | -0.2 | 0.4  | 93.9                        | 118.3    |
| 0                      | -0.2 | 0.4  | 94                          | 118.3    |
| 0                      | -0.2 | 0.5  | 94                          | 118.4    |
| 0                      | -0.2 | 0.4  | 94                          | 118.4    |
| -0.1                   | -0.2 | 0.4  | 94                          | 118.4    |
| -0.1                   | -0.2 | 0.3  | 94.1                        | 118.5    |
| -0.2                   | -0.1 | 0.2  | 94.1                        | 118.5    |
| -0.3                   | -0.1 | 0.1  | 94.1                        | 118.6    |
| -0.3                   | -0.1 | 0    | 94.1                        | 118.6    |
| -0.4                   | -0.1 | -0.1 | 94.1                        | 118.6    |
| -0.4                   | -0.1 | -0.1 | 94                          | 118.7    |
| -0.4                   | -0.1 | -0.2 | 94                          | 118.7    |
| -0.4                   | -0.1 | -0.2 | 94                          | 118.8    |
| -0.3                   | -0.1 | -0.1 | 94                          | 118.8    |
| -0.2                   | -0.1 | -0.1 | 94                          | 118.8    |
| -0.1                   | -0.1 | 0    | 94                          | 118.9    |
| 0                      | -0.1 | 0.1  | 94                          | 118.9    |
| 0.1                    | -0.1 | 0.1  | 94                          | 119.0    |
| 0.2                    | -0.1 | 0.2  | 94                          | 119.0    |
| 0.2                    | -0.1 | 0.2  | 94                          | 119.0    |
| 0.2                    | -0.1 | 0.2  | 94                          | 119.1    |
| 0.2                    | -0.1 | 0.2  | 94                          | 119.1    |
| 0.1                    | 0    | 0.2  | 94.1                        | 119.2    |
| 0                      | 0    | 0.1  | 94                          | 119.2    |
| -0.1                   | 0.1  | 0    | 94                          | 119.2    |

**Table A.1 (continued) :** Velocity vectors and water surface elevation changes over the time

| Velocity Vectors (m/s) |     |      | Water Surface Elevation (m) | Time (s) |
|------------------------|-----|------|-----------------------------|----------|
| u                      | v   | w    |                             |          |
| -0.3                   | 0.1 | 0    | 94                          | 119.3    |
| -0.4                   | 0.1 | -0.1 | 94                          | 119.3    |
| -0.5                   | 0.2 | -0.1 | 94                          | 119.4    |
| -0.6                   | 0.2 | -0.1 | 94                          | 119.4    |
| -0.7                   | 0.2 | -0.2 | 94                          | 119.4    |
| -0.7                   | 0.2 | -0.2 | 94                          | 119.5    |
| -0.7                   | 0.2 | -0.1 | 94                          | 119.5    |
| -0.6                   | 0.2 | -0.1 | 93.9                        | 119.6    |
| -0.6                   | 0.2 | -0.1 | 93.9                        | 119.6    |
| -0.6                   | 0.2 | 0    | 93.9                        | 119.6    |
| -0.6                   | 0.2 | 0    | 93.9                        | 119.7    |
| -0.5                   | 0.2 | 0.1  | 93.9                        | 119.7    |
| -0.5                   | 0.2 | 0.1  | 94                          | 119.8    |
| -0.5                   | 0.3 | 0.1  | 94                          | 119.8    |
| -0.5                   | 0.3 | 0.1  | 94                          | 119.8    |
| -0.5                   | 0.3 | 0.1  | 94                          | 119.9    |
| -0.6                   | 0.3 | 0.1  | 94                          | 119.9    |
| -0.6                   | 0.2 | 0.1  | 94                          | 120.0    |
| -0.7                   | 0.2 | 0.1  | 94                          | 120.0    |



## CURRICULUM VITAE



Name Surname : Vafa KHOOLOSI  
Place and Date of Birth : Urmia (IRAN) – 16.12.1982  
E-mail : Vafa1881@yahoo.com

EDUCATION :  
B.Sc. : 2005, IAU University of IRAN, Civil Engineering  
M.SC. : 2009, IAU University, Civil-Water Engineering

### PUBLICATION, PRESENTATION AND PATENTS ON THE THESIS:

- **Khoolosi, V., & Kabdaşli, S.** 2014. Modeling of surface water waves generated by a moving subaerial and submerged landslides. *11th international congress on advances in civil engineering ACE 2014*, Istanbul, Turkey
- **Khoolosi, V., & Kabdaşli, S.** 2015. Modeling and Comparison of Water Waves Caused by Landslides Into Reservoirs. 9th WORLD CONGRESS OF EWRA, "Water Resources Management in a Changing World: Challenges and Opportunities", 10-13 June 2015, Istanbul, Turkey
- **Khoolosi, V., & Kabdaşli, S.** 2016. 3d Numerical Simulation of Water Waves Generated By Landslides Into Dam Reservoirs. *12th international congress on advances in civil engineering ACE 2016*, Istanbul, Turkey
- **Khoolosi, V., & Kabdaşli, S.** 2016. Numerical Simulation of Impulsive Water Waves Generated by Subaerial and Submerged Landslides Incidents in Dam Reservoirs. *Civil Engineering Journal*, 2(10), 497-519.
- **Khoolosi, V., Kabdaşli, S., & Farrokhpour, S.** 2015. Modeling and Comparison of Water Waves Caused by Landslides into Reservoirs. *Watershed Management ASCE*, 72. Reston, Virginia, USA, doi:10.1061/9780784479322.007

