CONCEPTUAL LIQUEFIED NATURAL GAS (LNG) TERMINAL DESIGN FOR KUWAIT

A Thesis

by

FARES ALJEERAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2006

Major Subject: Ocean Engineering

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Chair of Committee, John M. Niedzwecki
Committee Members, Robert Stewart
Charles Aubeny
Head of Department, David V. Rosowsky

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ABSTRACT

Conceptual Liquefied Natural Gas (LNG) Terminal Design for Kuwait. (May 2006)

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Chair of Advisory Committee: Dr. John M. Niedzwecki

This research study investigated a new conceptual design for a modular structural configuration incorporating storage for Liquefied Natural Gas (LNG) within the base of the platform structure. The structure, referred to as a modified gravity base concrete structure (MGBCS), was envisioned specifically to be constructed at a suitable site off the coast of Kuwait. Coastal offshore bathometric information, environmental data and existing data on onshore facilities were examined in the site selection portion of the study. A finite element model of the MGBCS was developed using an industry standard finite element code that allows preliminary sizes of structural models to meet appropriate design codes. A variety of parametric and design load scenarios were investigated. This research tackles some preliminary issues that are adequate for an initial evaluation of the proposed design concept. The proposed design concept needs a lot more scrutiny in order to be sufficiently developed as a concept where it can be confirmed as a truly viable concept and investment. It was confirmed that quartering sea conditions, waves approaching at a 45 degree angle, are the most critical scenarios for the terminal based on maximum values and ranges of shears and moments. In addition, there are several interesting issues in this concept that should be further looked at for this design to be further developed. The limitations of our study must be mitigated in future designs if the proposed design concept is to be carried to the implementation stage.

ACKNOWLEDGMENTS

I would like to use this opportunity to thank my supervisor, Prof. John M. Niedzwecki, for his constant support. I also thank my supervisory committee for their dedication and concern.

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1. INTRODUCTION

Currently, many countries use oil as a main source of energy and market analysts expect the demand for oil to continue to increase. Based on this, it is wise to consider alternatives to oil including the wide use of natural gas which appears to be quite abundant. In terms of practicality, it can be economically converted to liquid form and transported by sea to sites near population centers where it would be converted back to gaseous form and distributed for use. Natural gas liquefies when it reaches the temperature of -160 ^{o} C (-256 ^{o} F) and it is stored without pressurization. Liquefied Natural Gas (LNG) requires 600 times less space than normal natural gas, which is easier to store and transport in vessels. Based on a study from (UH IELE 2003a), LNG is characterized as odorless, colorless, non-corrosive, non-toxic, and less dense than water. The UH IELE report also notes that natural gas could vaporize from LNG, leading to asphyxiation if it were in unventilated confinement. LNG is composed of 95% methane and 5% other elements (ethane, propane, butane, and nitrogen), as depicted in Fig. 1. Methane contains one atom of carbon and four atoms of hydrogen (CH_4).

The LNG value chain encompasses four main stages: exploration and production; liquefaction; shipping; and regasification and storage. Each of them plays an important role in determining the final cost of LNG. UH IELE 2003a places the LNG pricing range from production delivery to the United States at about $2.5-$3.5 per million Btu (MMBtu) (see Fig. 2). Qatar, Algeria, and Indonesia are the primary countries producing and selling LNG to the market. Safety is one crucial factor to consider in any offshore or onshore structure. Based on UH IELE 2003b report, there are four fundamental components which offer multiple layers of protection for the LNG structure against

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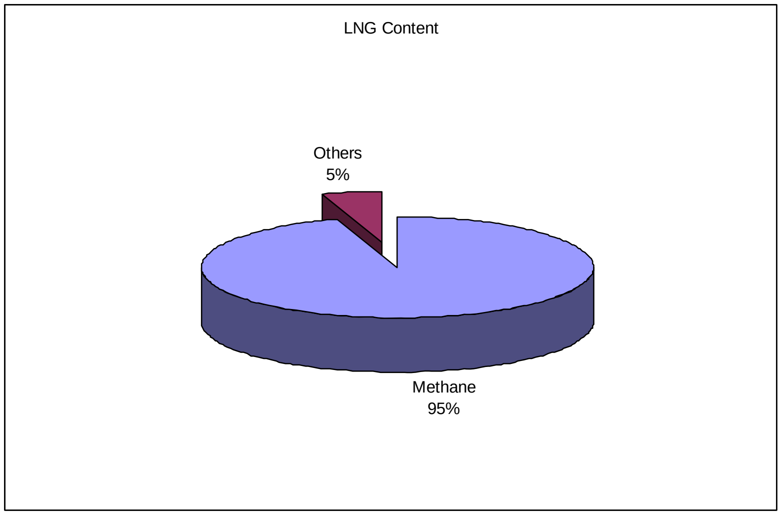


Fig. 1. LNG Content (UH IELE 2003a)

Fig. 2. LNG Value Chain (UH IELE 2003a)

hazards like explosion, vapor clouds, freezing liquid, rollover, and rapid phase transition. The fundamental components are primary containment, secondary containment, safeguard systems, and separation distance. In addition, UH IELE 2003b reported the flammable range of LNG, i.e. when it will burn, is when gas-to-air mixture is between a range of 5%-15% and this is illustrated in Fig. 3. Moreover, (American Bureau of Shipping 2004) has developed a document with information about safety issues that applies to any offshore LNG terminal. In addition, the auto ignition temperature of LNG is 540^o C (1004^o F), see Table 1. Table 2 contrasts the main advantages and disadvantages of LNG.

Currently, the Al-Shuaiba oil refinery in Kuwait burns and wastes huge amounts of natural gas that accompany oil drilling. Only a small fraction of this natural gas is being manufactured for domestic household consumption. Recently, many voices in the Kuwait Department of Energy have begun calling for the efficient utilization of this wasted resource. Many believe that utilizing technologies such as the liquefaction of natural gas would develop a new, lucrative source of income for the nation.

1.1 Literature Review

According to (UH IELE 2003a), three kinds of tanks are usually used for LNG carriers, but the one used most often is the spherical (Moss) design system, as confirmed in Fig. 4. The three types of tanks for containing LNG are illustrated in Fig. 5. The typical ship measures about 275 m in length, 43 m in width (beam) with an 11 m draft, and has a value of approximately $160 million per ship. LNG terminals utilize three different kinds of tanks—single containment, double containment, and full containment. The single containment tank shown in Fig. 6 includes and inner tank, which meets

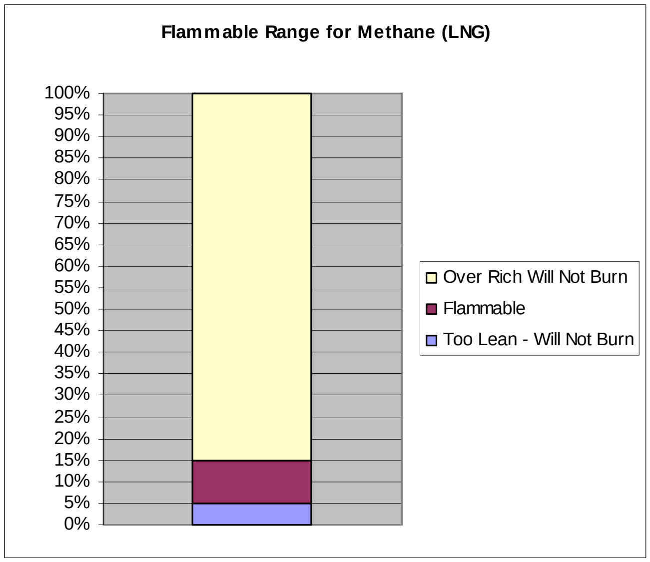


Fig. 3. Flammable Range for Methane (UH IELE 2003b)

Table 1 Autoignition Temperature of Liquid Fuels (UH IELE 2003b)

Fuel	Autoignition Temperature, F
LNG (primarily methane)	1004
LPG	850-950
Ethanol	793
Methanol	867
Gasoline	495
Diesel Fuel	Approx. 600

Table 2 Advantages and Disadvantages of LNG (UH IELE 2003b)

Advantages	Occupies up 600 times less space than regular natural gas at ambient temperature and pressure. Thus, it makes it easier to transport and store than natural gas.
	It can be stored above or below ground in specially designed double walled storage tanks.
	Can be transported over long distances via double-hulled LNG ships.
	LNG is widely spreading since it is replacing diesel in many heavy-duty trucks and buses and many new gas-fueled locomotives as a lower emissions alterative.
Disadvantages	"LNG operations are capital intensive. Upfront costs are large for construction of liquefaction facilities, purchasing specially designed LNG ships, and building regasification facilities."
	LNG consists of Methane, a primary component that is considered a greenhouse gas (greenhouse gases increases carbon level in the atmosphere).

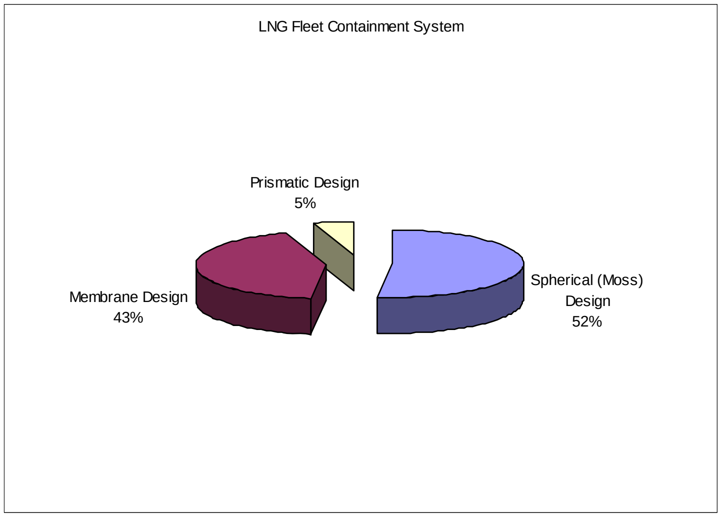


Fig. 4. LNG Fleet Containment System (UH IELE 2003a)

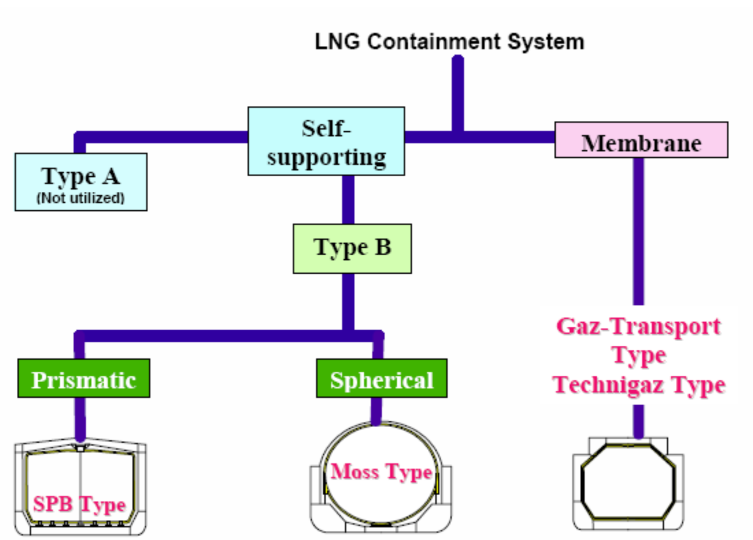


Fig. 5. Types of LNG Containment Systems (Pepper and Shah 2004)

Fig. 6. Single Containment Tanks (UH IELE 2003b)

requirements of the cryogenic temperature for LNG. However, the outer tank does not meet requirements if there is a leakage from the inner tank. Therefore, the second (Double Containment) and third (Full Containment) tanks meet requirements for both layers (inner and outer tank). The difference between the double containment tank (Fig. 7) and the full containment tank (Fig. 8) is that the full containment tank is capable of individually containing the stored LNG for both inner and outer tanks. Moreover, the concrete thickness of the outer tank is approximately 1 meter and it is located approximately 2 meters from the inner tank. However, in the double containment tank there is no space between the inner and outer tank. There are three different kinds of below-ground tanks for LNG-- in-ground, underground, and underground in-out (see Fig. 9). The above-ground tank type is typically used for LNG, because it is less expensive and easier to maintain than the below-ground tank type design which is widely used in Japan (UH IELE 2003b).

Wijngaarden et al. (2004) discuss the advantages of the concrete over the steel structural design regarding LNG facility design. In particular they note that concrete has a higher resistance to cryogenic temperatures and thermal shocks which is a crucial characteristic. Concrete structural designs can be more easily configured and constructed to accommodate LNG tanks and topside facilities. They are relatively low maintenance and have proven durability in marine environments, including excellent resistance to fatigue and buckling. On the other hand, challenges exist, and these include a few design codes specifically devoted to concrete offshore LNG terminal design, as well as quality control difficulties in the field construction. Information for various accident scenarios is

Fig. 7. Double Containment Tanks (UH IELE 2003b)

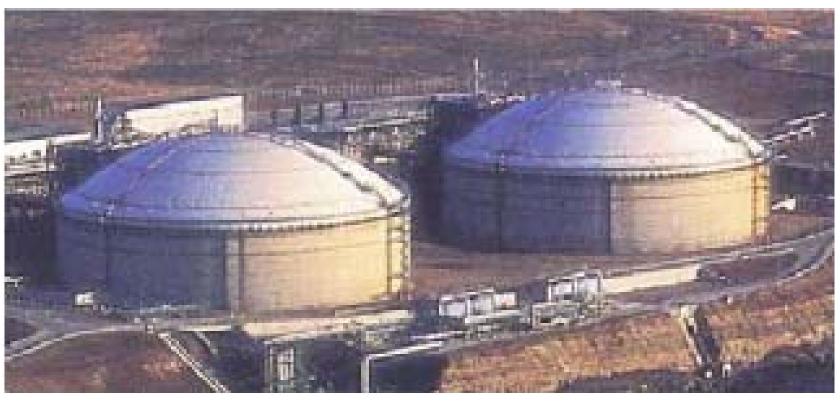


Fig. 8. Full Containment Tanks (UH IELE 2003b)

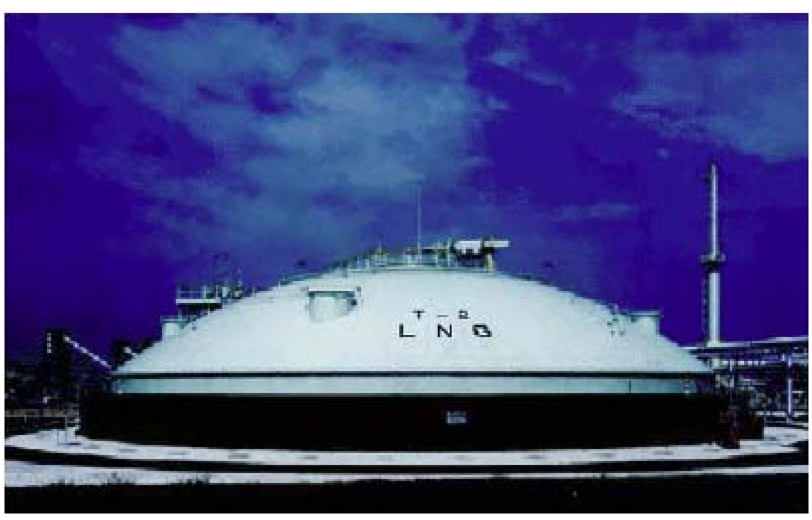


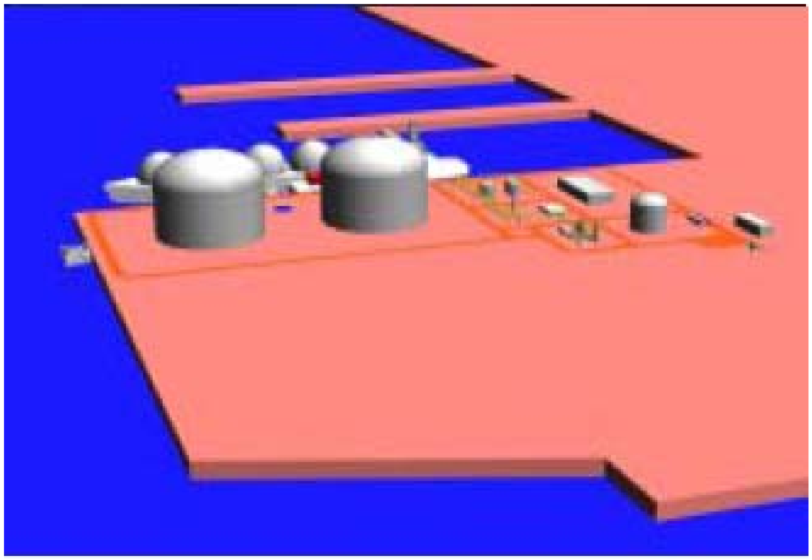
Fig. 9. Underground LNG Storage Tank (UH IELE 2003b)

limited regardless of the construction materials. Sensitive issues reported by Wijngaarden et al. (2004) include the deformation load induced from pre-stressing forces, shrinkage and creep, soil differential settlement, thermal gradient due to cryogenic temperatures, and hydration during concrete curing. Even so, there is significant experience with concrete structures in marine applications. Regardless of the offshore construction materials used and structural configuration, designing for various accident scenarios is problematic.

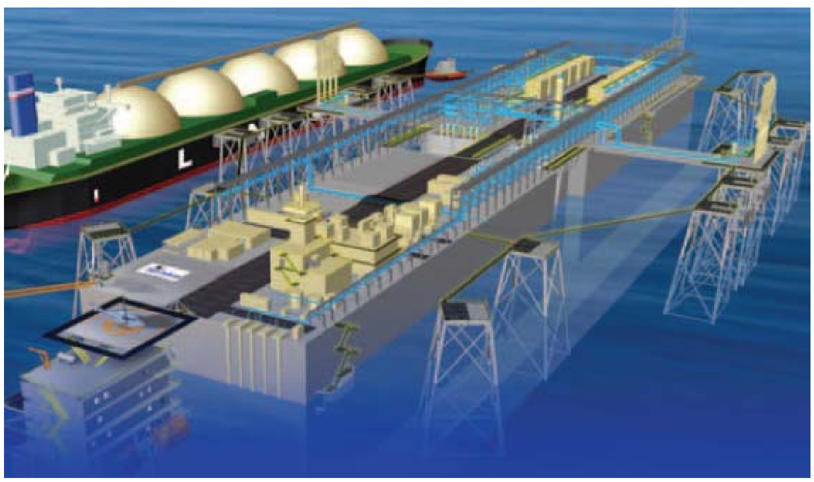
The most common design systems for the LNG terminal are an onshore system, an offshore gravity base structure (GBS), and offshore floating storage and regasification units (FSRU). These designs are depicted in Fig. 10. Onshore design constitutes a potential environmental risk in the event of natural and unanticipated disasters and the public out cry of (NIMBY)[1] has been significant. Therefore, an offshore rather than an onshore design was selected as the most pragmatic choice for this research investigation.

According to Shell Global Solutions (Said and Meijerink 2004), typical overall dimensions of a GBS with 250,000 m^3 LNG storage capacity located in 15 meters of water, would be approximately 340m long by 60m wide by 40m high. In addition, the minimum water depth for a GBS system is around 14-15 meters with respect to the berth of the LNG carrier. An example of a concrete gravity based structure is the one being constructed is the Chevron Texaco Port Pelican LNG Terminal. This GBS terminal system will be located in approximately 24 m of water and be close to 65km off the Louisiana coastline in the Gulf of Mexico (Collins and Borey 2004). Based on information from Shell Global Solutions, a typical FSRU barge ranges from 350 to 400 meters long, and 70 meters wide,

[1] Not in My Back Yard.



Onshore System



GBS

FSRU

Fig. 10. Three Different LNG Terminal Systems

and does not normally have a propulsion system[2]. Shell Global Solutions continues by noting that the storage capacity starts at 200,000 m^3 , and as the requirement increases, it may exceed 500,000 m^3 . A summary of the features that favors the use of a GBS system is presented in Table 3. As indicated in the table, the GBS is suitable for the shallow water sities, e.g. Kuwait.

Arup Energy has developed a novel concept (Fig. 11) for an offshore LNG terminal based on the typical onshore storage tank with some adaptations to meet the requirements for an offshore tank. This concept was developed for economical reasons. However, it has a space limitation on the floating deck that could constrain future upgrading of the facility.

Currently, there are several agencies responsible for establishing design and safety rules and standards for offshore LNG terminals. Det Norske Veritas (Waagaard and Veritas 2004) has a long history of certifying concrete structures in the marine environment in the Norwegian offshore. They have developed Offshore Standards for Classification of Concrete LNG Terminal, specifically DNV Offshore Standard C502 “Offshore Concrete Structures” and DNV OS-C503 “Offshore Concrete LNG Terminals.” In the United States, the American Bureau of Shipping has developed a document entitled: Guide for Building and Classing Offshore LNG Terminals. This latter document will be used as a guide for this study.

[2] “It will be towed from the shipyard and installed at its operational site”

Table 3 Advantages and Disadvantages of (GBS & FSRU) Systems (Wijngaarden et al. 2004)

GBS		FSRU	
Advantages	Disadvantages	Advantages	Disadvantages
Ideal solution for shallow water ($D \leq 20$m)	Higher cost than FSRU	Lower cost than GBS	Higher cost for maintenance
Easy to construct (rectangular shape)	Seabed bottom should be flat (or almost flat)	Good solution for deep water ($D \geq 40$m)	
No maintenance (in most of the cases)	Less flexibility than FSRU	Ideal solution for storm weather and hurricane environmental	
Concrete material which is very easy to deal with in Kuwait (very good experience)		Very flexible to locate it anywhere (with respect to the water depth)	
		Less risky and easier for the installation	

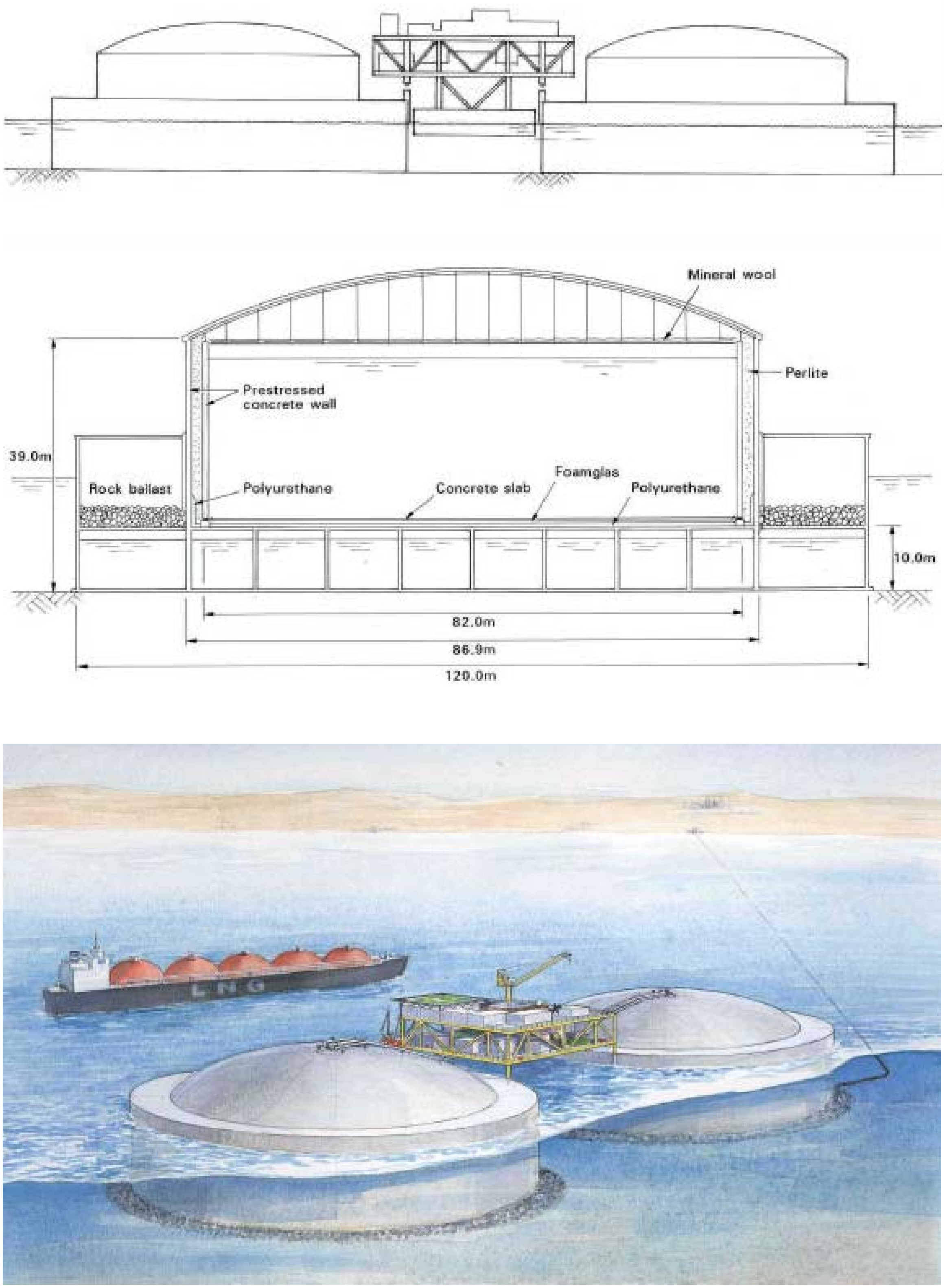


Fig. 11.A Novel Concept for Offshore LNG Storage Based on Primary Containment in Concrete

1.2 Thesis Objective

The design selection criteria will be based on data regarding existing onshore facilities, wave height, wind speed, current speed, and water depth along the coast of Kuwait. The location of Kuwait and a satellite image of the Kuwaiti coastline with potential locations for the proposed design are shown in Figs. 12 and 13. Bathymetric and environmental data were obtained for numbered locations. The range of environmental conditions is seasonally dependent and here only some typical ranges are presented. The wave height as reported in 1993 varies between 19 and 53 cm. Safar (1984) shows that the average wind speed varied between 5.8m/s and 3.4 m/s. Al-mutar et al. (2003) report that the current speed increases as one heads toward the southeast. After some reflection it appears that the optimal area for constructing the proposed terminal would be 3km east of location number 13 (see Fig. 14). In addition, data indicates that the depth of the proposed area, which was measured in 1999, is 20 meters. Moreover, the proposed site for the LNG terminal is close to the Al-Shuaiba port, as shown in Fig. 14, and it has a number of advantages.

The proposed MGBCS system is depicted in Fig. 15. The concept of this study accommodates issues pertaining to transportation and installation, as well as flexibility and overall cost considerations. This concept is entirely modular both in terms of the topside deck equipment units and in its expandability to accommodate large vessels. The proposed design has two major components crucial to the potential structure—tank structure and the vertical slab spanning the two tanks. The first component, tank structure, has a dual purpose: support (a column for the structure) and storage for the LNG. Based on Portland Cement Association (PCA 1993) guidelines, any major cracking

Fig. 12. Kuwait Coast Line (NASA 2004)

Fig. 13. Some Interesting Spots on Kuwait Coast Line (NASA 2004)

Fig. 14. The Best Spot for the GBS System (NASA 2004)

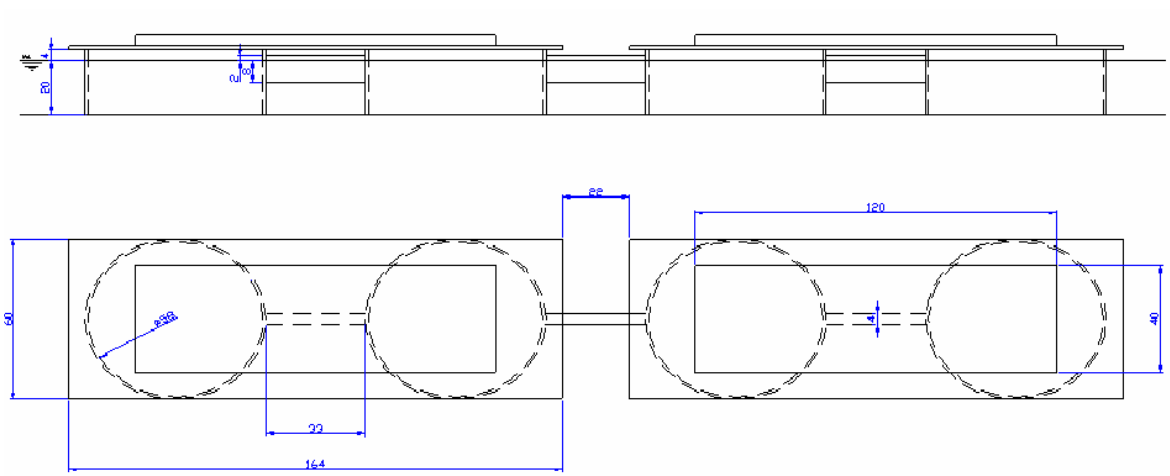


Fig. 15. Modified Gravity Base Concrete Structure (MGBCS)

in the storage tank is unacceptable. The design must adhere to the constraint of preventing an overload since an overload could potentially cause a crack in the tank that would lead to a hazardous LNG leakage. The second component, the vertical slab between the cylindrical tanks will act as a breakwater so that LNG tankers can be located on both sides of the platform. In this study, a variety of dead, live and environmental loads must be considered. Lateral forces from the waves and current will be addressed using Dean's Stream Function Theory. The 3-D modeling and simulation will utilize STAAD Pro, which is one of the most comprehensive and popular structural engineering software packages for analyzing and designing sophisticated structures. The finite element code STAAD Pro incorporates many important design codes including concrete (ACI), steel (AISC) and ASCE wind loads. Thus even for conceptual design the sizes of the proposed system will meet appropriate design codes.

2. THE COUNTRY OF KUWAIT

In the past, Kuwait was a small village and the people lived in peace and cooperation among one another, hunting fish and diving in the sea using traditional equipment to get their food. However, after the discovery of oil, numerous aspects of life changed and the standard of living improved dramatically. The first oil field in Kuwait was discovered in 1923 by an English Company. From 1899, the United Kingdom defended Kuwait, until Kuwait won independence from Britain on June 19, 1961.

2.1 General Information

Based on (C.I.A website), Kuwait is located at latitude 29^{o} 30’ N and longitude 45^{o} 45’ E and it lies between Iraq (border = 240 km) and Saudi Arabia (border = 222 km). It has a total land area of 17,820 sq km[3] and the land is nearly 90% flat dry desert with an undulating desert plain. The climate is extremely hot in summer, with briefperiods of cold in winter. The population is around 2 million, with the major natural resources being petroleum, natural gas, fish, and shrimp. Kuwait is located in the upper northwest of the Persian Gulf, and it is small, rich, and has a relatively open economy. It is estimated that Kuwait controls 10% of the world’s oil reserves (an equivalent of 96 billion barrels of oil). Oil returns account for approximately 50% of the Gross Domestic Product (GDP) (95% of exports revenues, and 80% of government income). Except for fish, Kuwait wholly depends on food exports. In 2004, the production of oil in Kuwait was 2.319 million bbl/day, the consumption of oil was 293,000 bbl/day (2003), and the export of oil was 1.97 million bbl/day (2003). In 2002, the natural gas production was 8.7 billion cu m, which is the same amount as annual consumption.

[3] A little bit smaller than New Jersey.

2.2 Coastal and Offshore Region

The coastline of Kuwait is 499 km long (C.I.A website) and there are four main ports. According to (http://www.mesteel.com), Shuwaikh port is the main commercial port, located at latitude 29^{o} 21' north, and longitude 47^{o} 56' east, and it is on the south side of Kuwait Bay. Al-Shuaiba port is located 60 km away from Kuwait City. Al-Shuaiba serves the Al-Shuaiba Industrial area; the largest industries being petrochemical oil refining, gas liquefaction, and cement manufacture. Abdulla port is operated by KNPC (Kuwait National Petroleum Company) for oil loading operations and it has 2 offshore loading berths and a harbor basin protected by piers. The last one is Al Ahmadi port which is located on the northwestern shore of the Persian Gulf, 30 km south of Kuwait City; it accommodates crude products and tankers.

Based on the Kuwait Embassy's website (http://kuwait-embassy.or.jp/english/envi/island.html), Kuwait has nine islands off the coastline: Bubiyab, Warba, Failaka, Miskan, Auhha, Umm Al-Maradim, Umm Al-Naml, Kubbar and Qaruh. The largest island is Bubiyan (863 km^2) and the soil on this island is 100% clay. It is located in the northeast section of the Persian Gulf.

2.2.1 Bathymetry and Soil Condition

Fig. 13 depicts all potential locations for the proposed LNG terminal, numbered 0-12. Our task is to choose the optimal location for constructing a GBS system. The aerial map aids in determining ocean depth in the Persian Gulf. Fig. 16 shows water depth based on the location number from Fig. 13. I believe that the optimal area for constructing the proposed terminal would be 3km east from location number 13 (see Fig. 14). In addition, it indicates that the depth of the proposed area, which was measured in 1999, is 20 meters. Moreover, Fig. 14 also shows that our proposed location is proximate to the Al-Shuaiba port, which is advantageous for the required pipelines of the LNG terminal. Based on the aerial map, the soil in location number 13 is clay. However, we could not obtain specific values for the bearing capacity of the soil in this region. Since our research investigates a new conceptual design for a modular structural configuration that incorporates storage for LNG, we assume a reasonable value based on clay soil.

2.2.2 Wind, Wave, Currents

Table 4 provides the average wave height for each location in Fig. 13; Fig. 17 graphically depicts the average wave height for all locations. Moreover, the chart in Fig. 18 shows the average wave height for location number 10 from Fig. 13, which is the closest point to location number 13 (Al-Shuaiba Port). All previous figures are based on Al-Muzani (1989). Fig. 19 from Safar (1984) shows that the average wind speed reached its maximum of 5.8 m/s in June, while it reached its minimum of 3.4 m/s in November. In addition, Fig. 20 shows the daily changes in wind speed from June to November for the period of 1962-1981[4]. Al-Mutar et al. (2003) state that current speed increases when heading southeast (see Fig. 21).

As previously noted, there are some disadvantages with the GBS system and it is logical to find another or modified system with more advantages. From this point of view, the modified GBS system illustrated in Fig. 15 is proposal in this study. The idea behind the modification is to reduce the effects of critical issues on transportation and installation, greater flexibility and lower cost than the typical GBS system. Hopefully, after this paper is written, more companies will focus on these types of tanks, developing more advanced LNG Terminal systems in the future.

[4] Based on Table 5, there is no much difference between the between the average wind speed on the MWL and on 100m above MWL.

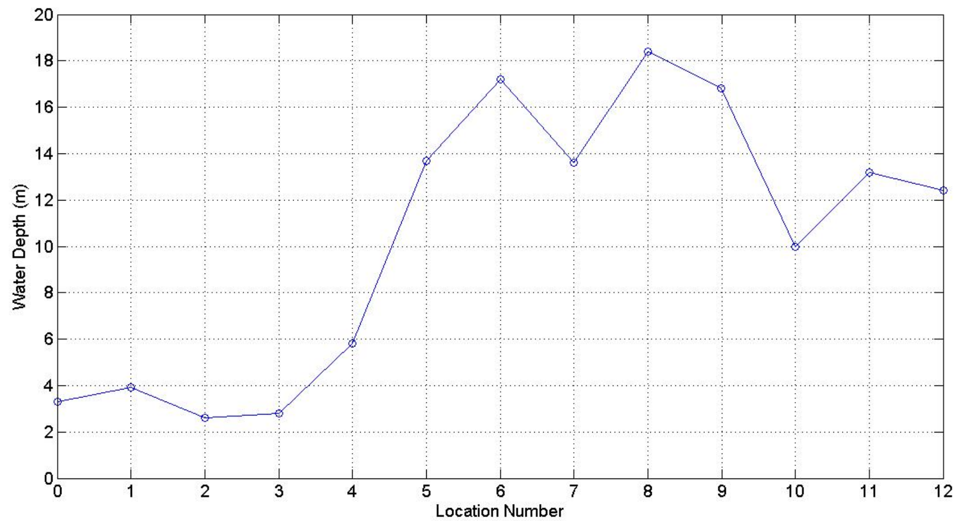


Fig. 16. Water Depth (m) for the Location Number

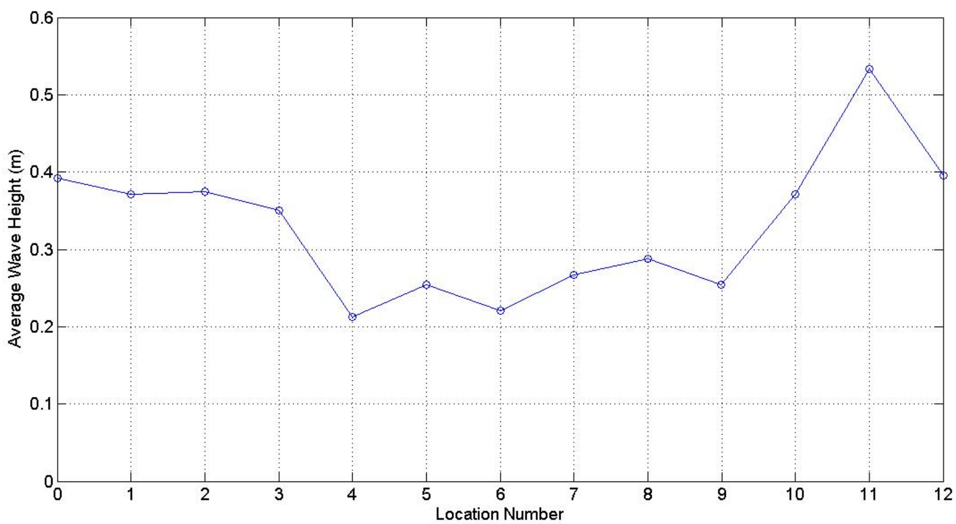


Fig. 17. Average Wave Height for the Location Number

Table 4 The Average Wave Height (in meters) in Kuwait (1993)

No.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	average
0	.70	.50	.70	.20	.35	.15	.30	.60	.10	.20	.20	.70	.3917
1	.60	.60	.90	.10	.20	.05	.30	.80	.05	.05	.10	.70	.3708
2	.70	.60	.40	.15	.40	.10	.30	.80	.05	.10	.20	.70	.3750
3	.80	.50	.30	.05	.30	.10	.20	.80	.10	.20	.25	.60	.3500
4	.20	.10	.05	.10	.20	.15	.10	.80	.10	.10	.15	.50	.2125
5	.20	.10	.15	.05	.15	.40	.20	.10	.10	.80	.10	.70	.2542
6	.15	.20	.10	.15	.25	.40	.40	.15	.15	.15	.05	.50	.2208
7	.20	.10	.20	.15	.25	.40	.50	.40	.30	.15	.05	.50	.2667
8	.05	.10	.10	.10	.30	.60	.40	.50	.30	.30	.10	.60	.2875
9	.15	.15	.30	.15	.45	.50	.20	.45	.20	.30	.10	.10	.2542
10	.10	.70	.10	.20	.25	.40	.70	.50	.50	.50	.40	.10	.3708
11	.10	.80	.05	.60	.25	.40	.75	.50	.65	1.20	.90	.20	.5333
12	.10	.70	.05	.50	.50	.30	.75	.50	.80	.05	.30	.20	.3958
average	.3115	.3962	.2615	.1923	.2962	.3038	.3923	.5308	.2615	.3154	.2231	.4692	.3295

The purpose of our study is to initiate a design concept. The idea of the study is in its infancy and the outcome of the research is at a preliminary stage. Our study tackles some aspects of a potential LNG design. There are other aspects that must be factored in and considered if the modified concept is to be implemented.

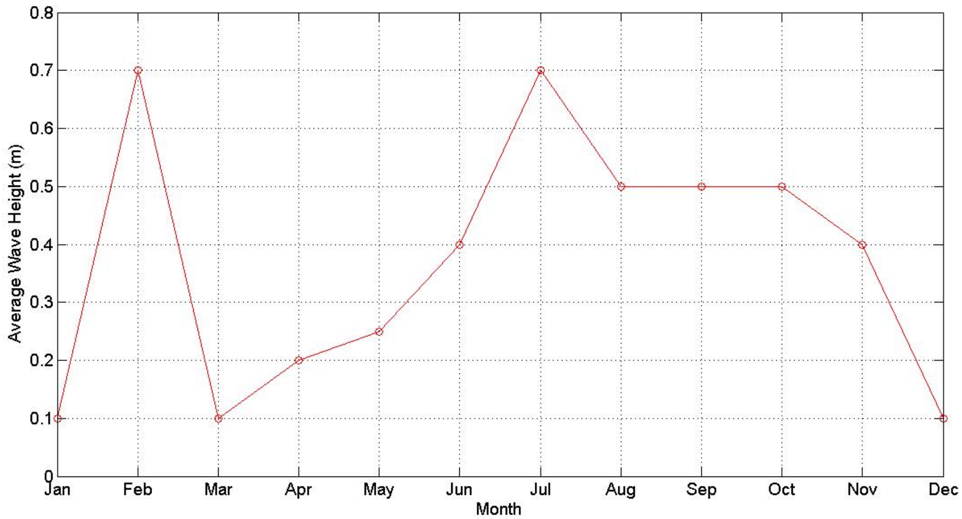


Fig. 18. Average Wave Height for Location Number 10

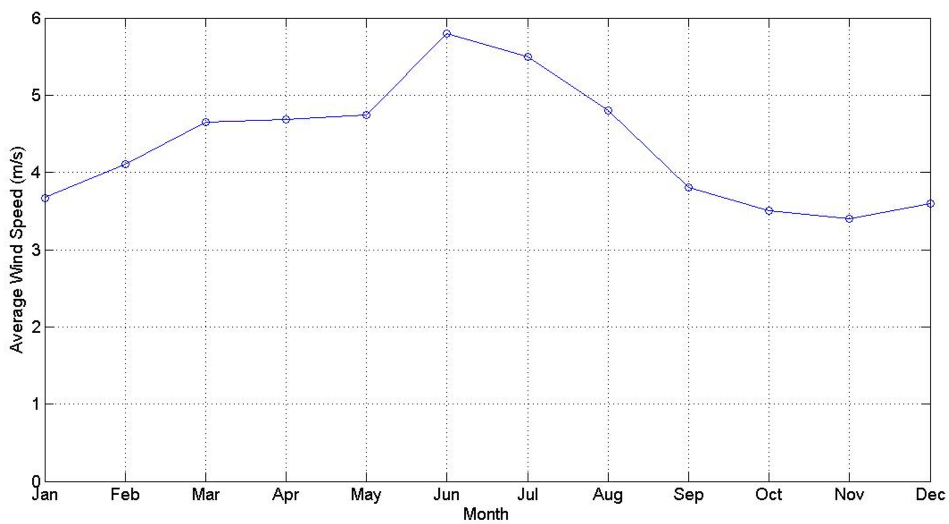


Fig. 19. The Annual Variation of Wind Speed as Recorded by the Weather Forecasting Station of Kuwait International Airport for the Period of 1962-1980 (Figures Are Measured on an Hourly Basis for 24 Hours).

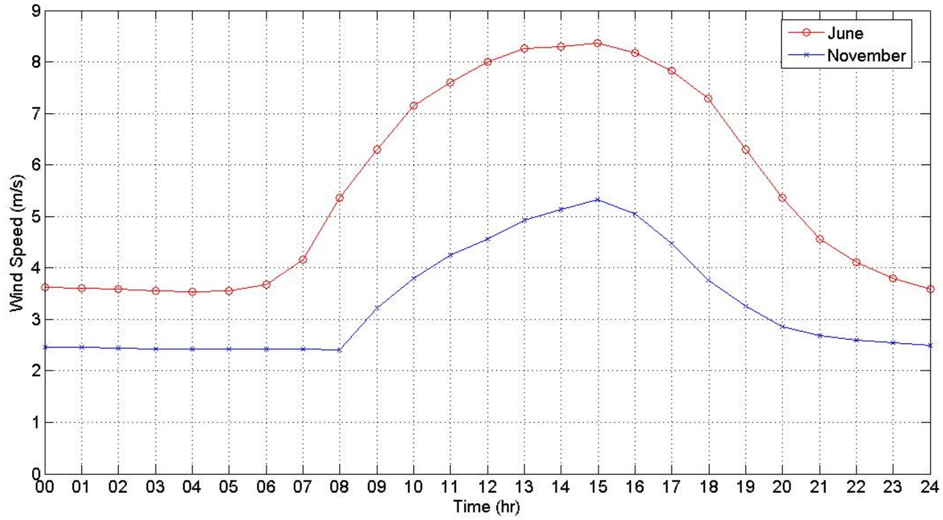


Fig. 20. The Daily Variation of Wind Speed Between June and November for the Period of 1962-1981. Figures Are Measured by the Weather Forecasting Station of Kuwait International Airport.

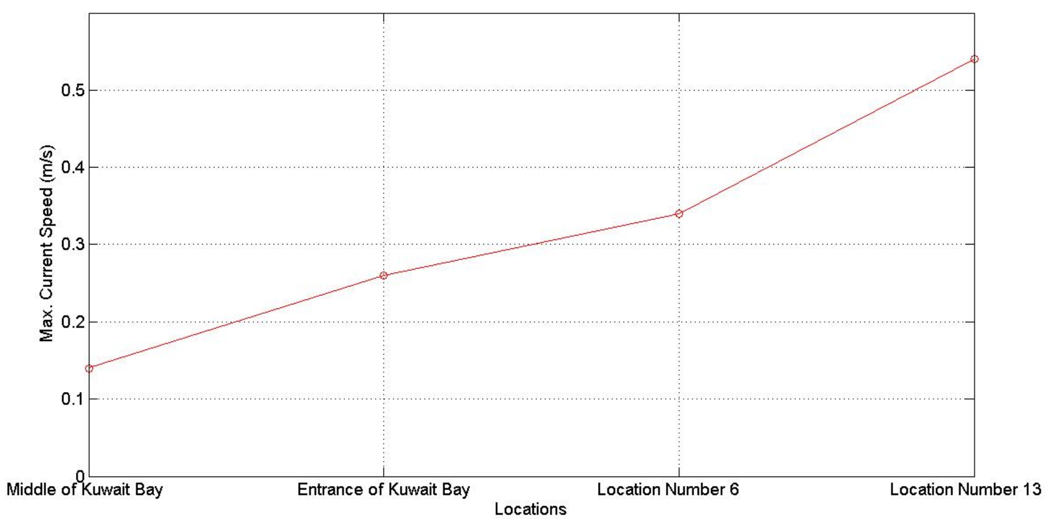


Fig. 21. Maximum Current Speed (m/s) for Some Locations

Table 5 Comparison Between the Average Wind Speed on the MWL and on 100m Above MWL (m/s)

Time	June (1982)		July (1982)	
	MWL	100m above MWL	MWL	100m above MWL
2:00 am	3.67	5.32	3.62	4.96
2:00 pm	7.78	8.05	7.2	7.78

3. ENGINEERING PARAMETER ESTIMATES

The MGBCS is a new concept and there is no reference in the literature that we can use for the structure parameters. Based on this, the best way to solve this problem is to compare it with similar different designs based on functionality and beneficially for the structure. Table 6 depicts small comparison regarding dimensions between a typical GBS system and the new concept MGBCS.

3.1 LNG Terminal Concept

The terminal concept comes from the Gravity Base Structure (GBS) which is a very stable structural system and an ideal solution for the shallow waters of Kuwait (Depth < 20 m); see Fig. 22. However, some disadvantages of the GBS system are its relative costliness and less flexibility compared to other systems. Based on this knowledge, we use a modified gravity base concrete structure (MGBSC) to meet these requirements, see Fig. 23. The tank system in MGBSC employs the same concept as an onshore tank system, but with some modifications on the layers of the tank. Previous information indicates there is a double containment tank for LNG, which has two layers for the wall of the tank. The inner layer is 9% nickel steel to contain the LNG under normal operation and the outer layer provides reinforcement concrete to control any leakage from the inner layer; see Fig. 24. According to the new design concept, the tank is sunk under the water and carries the liquefaction facility that is above sea water level to protect it from wave impact during operations between the terminal and the vessel. The primary difference between the normal double tank and the new one will be the outside atmosphere, composed of the load of the deck and the load of the waves.

Table 6 Dimensions Comparison Between GBS and MGBCS

	GBS	MGBCS
Length	350m	350m
Width	52.4m	60m
Height	39m	30m

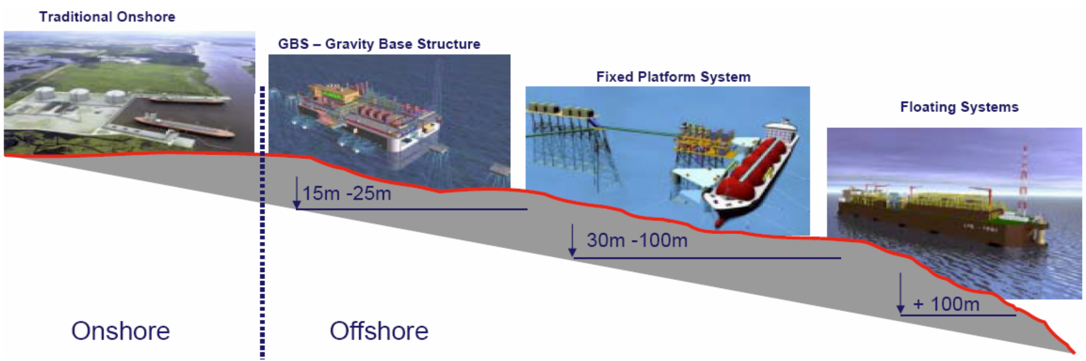


Fig. 22. GBS System Comparing with Other Systems (AKER KVAERNER 2005)

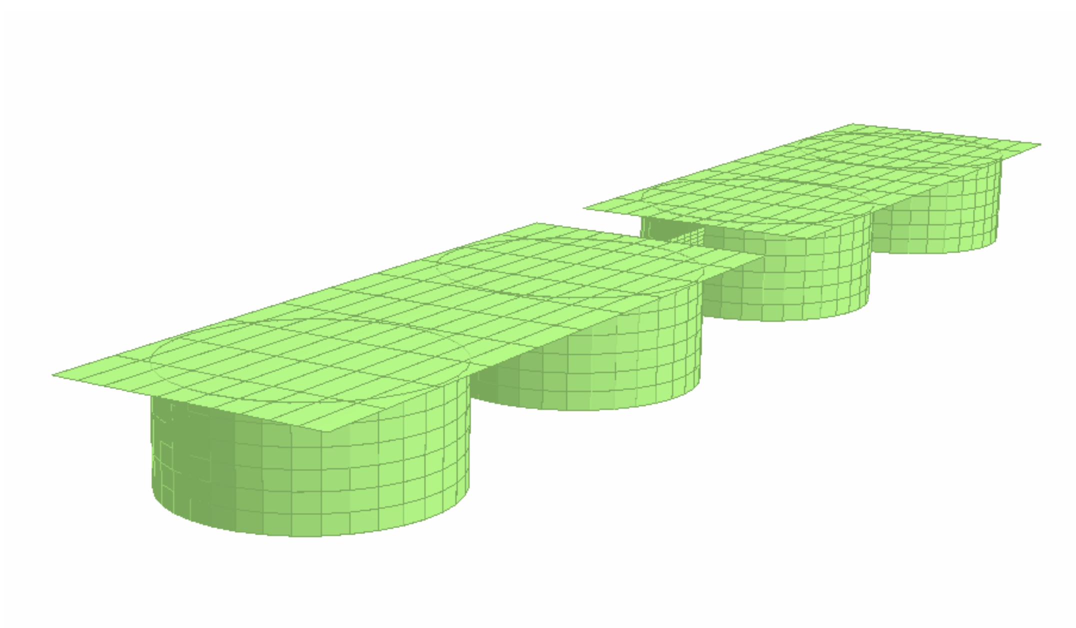


Fig. 23. MGBCS (Modified Gravity Base Concrete Structure)

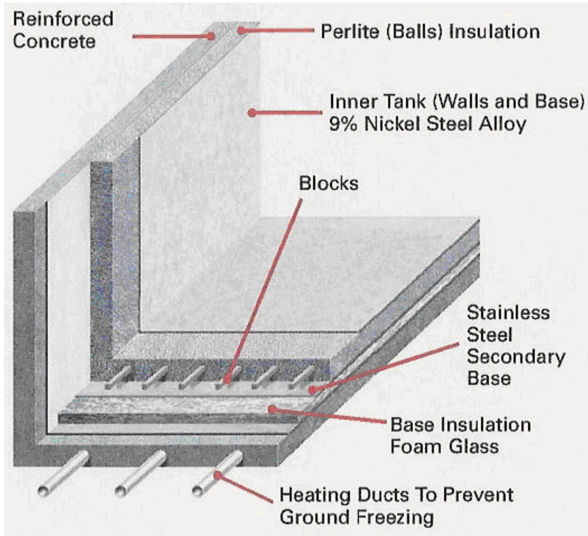


Fig. 24. A Cross Section of Storage Tank Wall (http://www.lngfacts.org)

3.2 Preliminary Sizing of the MGBCS

Based on Rupert Taylor[5], the typical double containment tank has a thickness 25mm of 9% nickel steel and outer wall thickness of 0.8m + 10% to take into account various pieces on the tank, such as insulation and resilient blanket. Accordingly, we assumed that the thickness of the new tank should be 2m and 95% of it will be concrete to protect it from the waves load. However, we did not include the insulation in the STAAD Pro and we assumed that the tank is 2m solid concrete according to the software option limitation. Beams and columns inside the tank and inside the wall of the tank hold the liquefaction facility located on the deck. Therefore, there will be direct contact between the LNG and the concrete (columns and beams). From previous information, we know that concrete has a higher resistance to cryogenic temperatures, so there will be no problems with direct contact between the LNG at -160 ^{o} C (-256 ^{o} F) and the concrete. The roof of the tank is flat and not domed like a typical LNG tank, due to the deck above. According to Rupert Taylor, dome roof thickness varies between 0.4~0.6m and the basement slab is 1.5m; however, the flat roof thickness of the design is 0.13m based on the analysis in STAAD Pro Software. According to STAAD Pro 2005, Table 7 presents the input data for the concept and the assumptions result sizes of slabs, beams, and columns. A typical GBS system has storage capacity = 250,000 m^3 ; based on this, the design will have 4 tanks, with each one having storage capacity = 68,500 m^3 . Based on ABS, the air gap is at least 1.5m (5ft) between the deck and the maximum wave crest elevation. According to data that we have gathered, we assume that the maximum wave height in Kuwait is 6m. The assumption for the necessary height between the deck and the sea water

[5] Business Development Manager (Gas & LNG) Shell Global Solutions (Malaysia).

Table 7 STAAD Pro 2005 Input Data

Code	Material	Size	Support
ACI	Concrete - fc =2812.3 ton/m ^{2} Steel - grade (420) - fy = 42184.4 ton/m ^{2} Max main reinforcement bar = 32 Min main reinforcement bar = 16 Min secondary reinforcement = 12	Slab thickness = 0.13m Corner slab thickness = 0.09m Vertical Slab thickness = 1m Tank wall thickness = 2m Beams = 2m x 3.5m Columns = 2m x 2m Circular column = 2m	Fixed

level is then 7.5m. According to the small period of wave height data that we have, we will figure 7.5m for the height between the deck and the sea water level. Given this basic data, the height of the tank is = 7.5m + sea depth (20m) - basement slab (1.5m) = 26m. Next, we calculate the radius of the tank which is = $\sqrt{68500/(\pi \times 26)}$ = 29m. The concept has two liquefaction facilities, two decks, and four storage LNG tanks. Each liquefaction facility sits on one deck, and each deck has two storage LNG tanks underneath. Each liquefaction facility will serve two tanks--a relatively independent system that can serve two vessels at the same time. This provides more future flexibility because of independent decks. According to Rupert Taylor, the onshore plant (liquefaction facility) size is about 250m x 100m and the floating plant (liquefaction facility) size is about 200m x 50m, with each tank = 125,000 m^3. Based on this, the assumed size for the new liquefaction facility is 134m x 40m for serving two tanks, each of which is = 68,500 m^3. Rupert Taylor notes that the weight for the typical liquefaction facility is around 10,000 Mton. We assume that the weight for our liquefaction facility is = 7,000 Mton. According to ABS[6], the living space area is to be located far from hazardous areas and it is not recommended that it be above or below the LNG or process areas, see Fig. 25. Based on this, the design will have only a liquefaction facility on the deck. In addition, we added a vertical slab underneath the deck and connected between the two storage tanks. The benefit of this slab is to support the structure against lateral force, while simultaneously acting as breakwater for the LNG carrier. Moreover, this slab may use (put) some holes in it to reduce interaction due to tapping of waves (wave attenuation).

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[6] American Bureau of Shipping.

Fig. 25. LNG Terminal with Living Quarter That Is Located Outside of Hazardous Areas (Arup Energy 2004)

Specific considerations were applied to this structure: dead load, live load, and environmental load. However, other aspects not covered include current load, analyzing the basement slab (thickness = 1.5m) underneath the structure, analyzing the foundations (shallow foundation or piles) and analyzing the whole structure (two decks and four tanks) in STAAD Pro. When first analyzing the structure which is in Fig. 26, one notes that the deflections on the corners are very high because the slabs are supported only on two directions (not four directions as usual). Then, we decrease the thickness and the dimensions to solve this problem, see Fig. 27. Furthermore, the span inside each tank was very long (58m) and the loads on each beam were quite high. The solution was to place circular columns inside each tank to support the beams. The concept was designed, keeping in mind three major scenarios: empty storage tank, half full storage tank, and completely full storage tank. We analyzed the structure based on Airy, Stokes and Stream functions in different wave directions (0^o, 45^o and 90^o) with respect to the wave positions. This study has several limitations that could provide clear directions for future research. Because it is not the full version, the chosen simulation software (STAAD Pro version 2005) could not be used to analyze and simulate the whole proposed structure. Thus, roughly half of the proposed concept was included in the software simulation (2 tanks and one deck). Moreover, also due to a software limitation, the effect of wave currents could not be included in the software simulation. Finally, an exact and total cost for the proposed off-shore structure could not be feasibly estimated. The cost of some of raw materials could be estimated; however, the cost of several elements of the proposed design concept could not be estimated at this stage of the study. Examples of these elements are labor cost, land (price/rent), and consultation fees, among others.

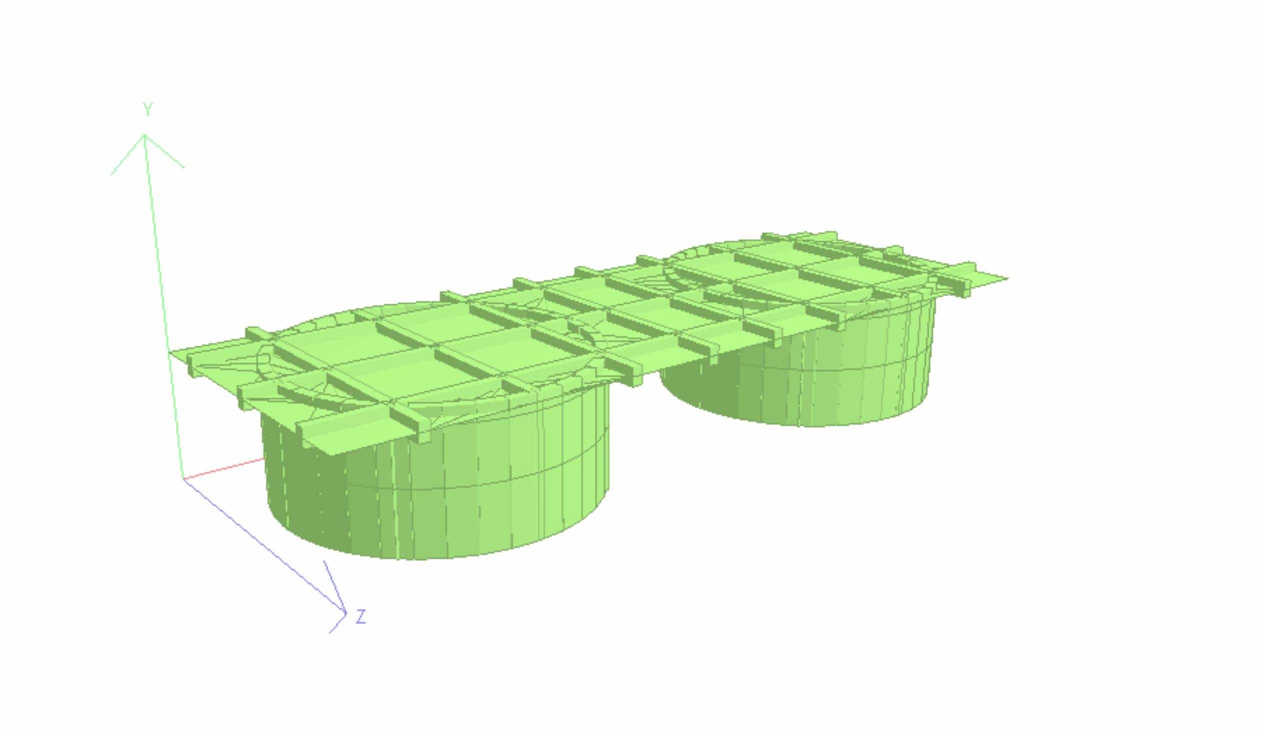


Fig. 26. The First Modified Concept

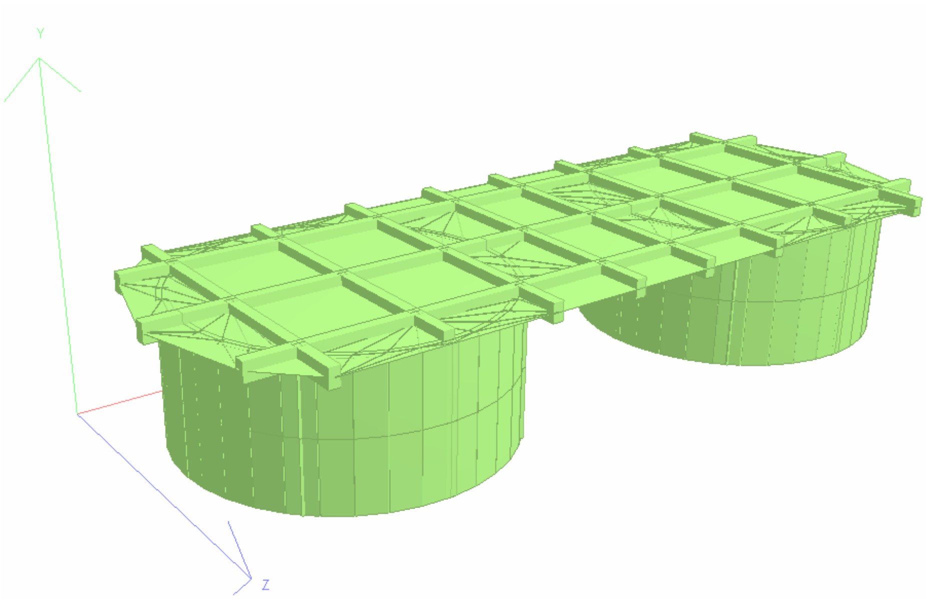


Fig. 27. The Final Concept

The study assumes that there is no vessel nearby our proposed design structure. This assumption was made for the sake of simplicity. Our approach is justified since our study it is the first stage toward a more comprehensive design that is limited unrealistic assumptions. The limitations of our study must be mitigated in future designs if the proposed design concept is to be carried to the implementation stage. Table 8 gives you an idea of how big is the LNG carrier and you can image of how it can change the loads inside the structure based on the waves that will be between the vessel and the deck if we included in the design stage.

3.3 Offshore Environment

One of the crucial factors that we have to be considered in this investigation is the environmental factors like, winds, waves, currents, sea temperatures, and salinity. For simplifying the new concept investigation, the research is included some of these factors, which are winds and waves. Due to some difficulties in Offshore Program Generator (version 1.8.8), the currents will not be included in this research. However, we could use a uniform profile in later stage of calculation. In the pervious sections, some information has been mentioned on winds, waves, currents as in average values. For designing environmental condition purpose, the ideal interval for getting the maximum designing data is the interval of (100 years), according to ABS. Due to less information on these data for this period of time (100 years), we estimated the maximum wind speed and the maximum wave height according to these equations

$$V_{wind} = V_{\max} \times C_{gust} \times C_{\substack{over \\ water}} \quad (1)$$

$$H_{wave} = H_{\max} \times C_{\max} \times C_{\substack{vessel \\ amp}} \quad (2)$$

Table 8 LNG Carrier Main Particulars (SAMSUNG 2004)

	Length Over All	Length Between Perpendicular	Breadth	Depth to Upper Deck	Draught, Design (Td)	Service Speed
138,200 m^3 LNG Carrier	278.8 m	266.0 m	42.6 m	26.0 m	11.35 m	19.5 kts
147,400 m^3 LNG Carrier	285.0 m	272.04 m	43.4 m	26.0 m	11.5 m	19.5 kts
165,000 m^3 LNG Carrier	299.5 m	286.0 m	46.0 m	26.0 m	11.5 m	19.5 kts
205,300 m^3 LNG Carrier	315.0 m	302.0 m	50.0 m	27.0 m	12.0 m	19.5 kts
225,000 m^3 LNG Carrier	337.0 m	323.0 m	50.6 m	27.0 m	12.0 m	19.5 kts
250,000 m^3 LNG Carrier	332.0 m	318.0 m	51.0 m	30.0 m	13.5 m	19.5 kts

3.4 Loads on the Structure

Loads are playing very important roles on this concept. For simplification, we categorized the loads based on their directions, vertical loads, horizontal loads, and combination. The vertical loads are dead loads (self weight – liquefaction facility), and live loads (persons on board). In addition, the horizontal loads are winds, waves, and currents. Finally, the combination load is the Liquefied Natural Gas (LNG). It causes horizontal loads on the wall of the tank and vertical loads on the basement slab of the tank. All these loads are affecting the whole structure and it should be considered. The most critical and maybe the most important relationship between the loads is between the horizontal loads that came from Liquefied Natural Gas and the horizontal loads that came from waves, winds, and currents. The main scenarios of the LNG inside any of these tanks are empty, half full, and completely full of LNG. However, the second part (waves, winds, and currents) is the most difficult one to investigate and analyze based on their randomness values and directions. For making things easier, we applied the winds in one direction and the waves in three different directions (0^o, 45^o and 90^o) with three different methods (Airy, Stream, and Stokes). The winds direction is applying on the long side of the structure which is 90^o.

3.4.1 Wave and Wind Loads

The main horizontal loads that are affected on the structure are wave and wind loads. The wave loads are applied based on three different wave theories (Airy, Stokes, and Stream) in three different wave directions (0^o, 45^o and 90^o). Table 9 shows the differences between Airy, Stokes, and Stream Function Theories. Moreover, Fig. 28 demonstrates the wave profile according to these wave theories; one will note very little

Table 9 Comparison Between Airy, Stokes, and Stream Function Wave Theories

Name	Method	Depth (m)	Wave Height (m)	Wave period (s)	Wave Length (m)	Wave Celerity (m/s)
Airy	Theoretical	20	6	6	55.06	9.18
Stokes 5	Theoretical	20	6	6	60.3	9.61
Stream 3, 9	Numerical	20	6	6	60.6	10.1

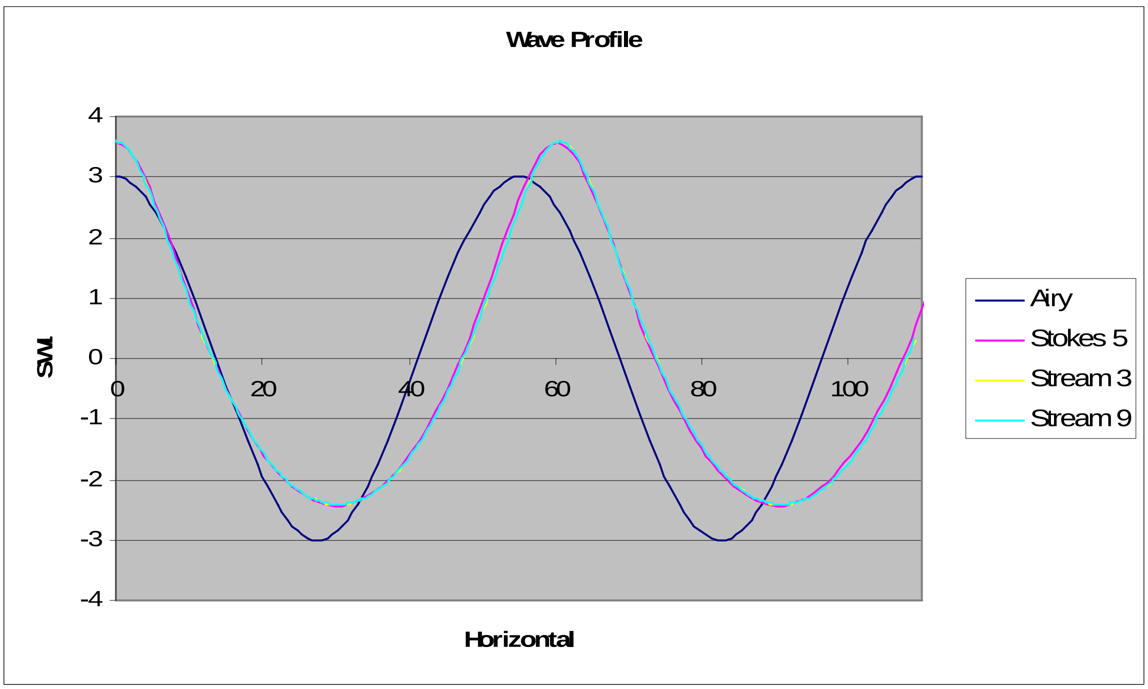


Fig. 28. Wave Profile for Our Spot Location

difference between the wave profile of stream 3 and stream 9. This wave profile would typically be applied on the structural area based on the data in Table 9.In addition, Fig. 29 shows the recommended wave theory order for stream function based on wave height, wave period and depth. Based on this information, we applied three different wave theories (Airy, Stokes & Stream) in three different wave directions (0^o, 45^o and 90^o) on the structure to see the differences in shear and moment forces on selected critical points on the structure. Offshore Program Generator is using Morison's Equations

$$f = C_D \frac{1}{2} \rho |u| u D dz + C_M \rho \dot{u} \frac{\pi D^2}{4} dz \qquad (3)$$

to calculate the drag force and the inertia force. According to Morison, a wave motion that exerts a force on a section of a pile consists of a drag force and an inertia force. The drag force is similar to the drag applied on a body that is subjected to a steady flow of real fluid resulting from a wake formation behind the body. The inertia force is analogous to a force exerted on a body which is subjected to a uniformly accelerated flow of an idea fluid. Based on API, it is customary to use $C_M = 2$ and $C_D = 1.6$ in Eq 1.3 for the calculation of the total force acting on a cylinder in a flow with constant acceleration.

The wind loads are applied horizontally on the structure in 90°. Based on ABS, the factor of safety for wind load that we used for this concept is 1.3. In addition, we applied 31.9 m/s as a maximum wind speed, according to (www.ncdc.noaa.gov). The wind pressure profile is applied on the structure and generated by STAAD Pro based on ASCE 2002 code. Table 10 shows a small summary of the wave and wind loads that are applied on the structure.

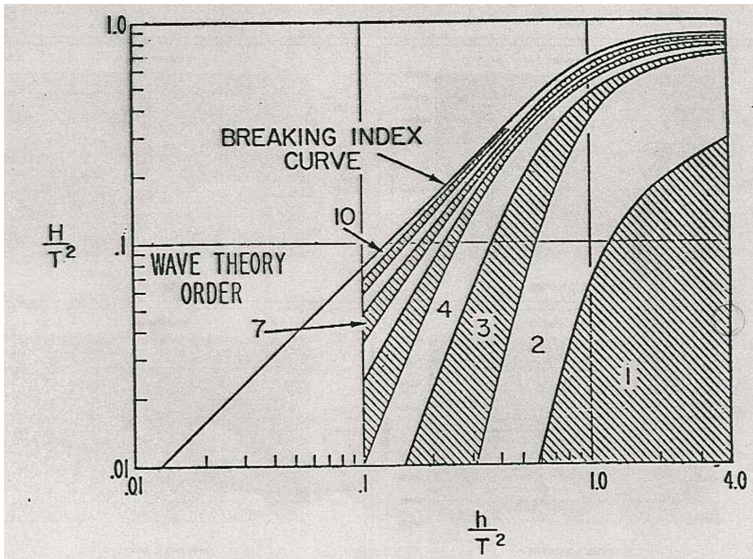


Fig. 29. Recommended Order of Wave Theory

Table 10 Wind and Wave Loads

Type of Load		Factor of Safety	
Wind Load	ASCE 2002	$C_{gust} = 1.2$ $C_{over\ water} = 1.1$	$V_{\max} = 31.9$ m/s[7]
Wave Load	Airy, Stokes, and Stream function	$C_{\max} = 1.86$ $C_{vessel\ amp} = 2$	$H_{\max} = 1.4$ m, T = 6 sec[8] Wave Dir. (0 , 45, and 90 degrees) Wave Pos. (0 – 180, interval 30)

[7] Maximum wind speed based on (www.ncdc.noaa.gov)
[8] According to (Al-mutar et al. 2003)

3.4.2 Dead and Live Loads

Typically, any structure has dead loads and live loads that have to be considered. In this concept, the vertical dead loads are selfweight and liquefaction facility. Moreover, the vertical live load is the persons that will be on board. Based on ABS, the range of POB (Persons on Board) for offshore LNG terminal is 30-50. We applied three different scenarios, empty tank, half full tank, and completely full tank (see Table 11) regarding the horizontal load of LNG that is applied on the wall of the tank. Table 12 shows the dead and live loads that are included in the concept.

Table 11 Different Scenarios for MGBCS

Case	Offshore Environmental	LNG Tank	Load
1	Airy – Wave Dir. 0^o Wave Dir. 45^o Wave Dir. 90^o	Empty Tank Half Full Tank Completely Full Tank	Dead Load Live Load Wind Load Wave Load
2	Stokes 5 – Wave Dir. 0^o Wave Dir. 45^o Wave Dir. 90^o	Empty Tank Half Full Tank Completely Full Tank	Dead Load Live Load Wind Load Wave Load
3	Stream 9 – Wave Dir. 0^o Wave Dir. 45^o Wave Dir. 90^o	Empty Tank Half Full Tank Completely Full Tank	Dead Load Live Load Wind Load Wave Load

Table 12 Dead, Live, and LNG Loads

Type of Load		Factor of Safety	
Dead Load	ABS & ACI	1.4	Selfweight Liquefaction Facility on each deck (7,000 ton)
Live Load	ABS & ACI	1.7	Persons on Board on each deck (POB) = 30
LNG Load	ABS & ACI	1.5	LNG Density = 0.45 T/m^3

4. ANALYSIS OF THE LNG TERMINAL CONCEPT

We chose to use STAAD Pro 2005, a popular and widely used structural engineering software package. Our decision to use a software package instead of conventional manual methods is justified given the complex nature of the interaction between the proposed offshore terminal and the loads that are applied to the structure. STAAD Pro has the ability to analyze and design sophisticated structures based on advanced finite element techniques.

4.1 Simulation Software

The Finite element method is a mathematical approximation procedure, which was first introduced in structural mechanics (see for Mori 1983, Huston and Passerello 1984, Norrie 1973). In this method, the domain is divided into uniform finite elements called sub-domains. The so-called "trail solution" is functionally applied over the domain element by element. Over time, finite element techniques gained status and have become an important engineering and scientific tools. As previously indicated, the algorithm (procedure) of finite elements methods is rather straightforward. The procedure starts with modeling a mathematical problem by dividing it into smaller finite elements. Then, mathematical analyses are performed on these smaller finite elements. Finally, a solution to the original (whole, undivided) problem is obtained through assembling the elements, which collectively represent the whole original problem. The original structure (body of the problem) is the assemblage of these finite elements that are connected at a finite number of joints, which are known as "Nodes" or "Nodal Points." In addition, the properties of the entire structure (body) are obtained through formulating and combining the individual properties of the finite elements. Finite element technique is viewed as a simple, yet ingenious, procedure, which focuses on the formulation of properties of the constituent elements of the body instead of solving the problem for the entire body in a single operation. The accuracy of the modeling can be improved by increasing the number of elements.

Analytical methods are rendered useless in many complex problems requiring cumbersome mathematical formulations. Thus, finite element method is a powerful tool for obtaining numerical solutions for such complex problems. Hence, finite element method is commonly used in many scientific and engineering disciplines in which complex problems are frequently encountered. Because finite element method uses a common procedure for combining the finite elements of a structure, the modular structure of the method became widely exploited in certain engineering disciplines. For example, it is widely employed in structural mechanical problems such as truss, beam, and plane elastic problems. For obtaining equations of equilibrium for an entire structure, the individual equilibrium equations of the elements are combined in a manner that ensures continuity at each node. Then, deepening the domain of application, the necessary boundary conditions are imposed to solve equilibrium equations for the desired variables, such as stress, strain, temperature distribution or velocity flow.

STAAD Pro is one of the most popular structural engineering software programs for 3D modeling, analyzing and designing sophisticated structures. It possesses the ability to analyze and design beams, trusses, frames, slabs, foundations, piles, columns, and complex structures. Moreover, it is capable of analyzing and designing multi- material structures, like aluminum, steel, timber and concrete structures. In addition, it incorporates important design codes including concrete (ACI), steel (AISC) and ASCE wind loads. Furthermore, these models can incorporate numerous load types with many different types of scenarios at the same time. Finally, another outstanding feature of STAAD Pro is its compatibility with Windows the most powerful operating system in current use.

For the wave loads, we used the Offshore Program Generator (version 1.8.8) to get the effect that came from the waves to the structure. The Offshore Program Generator is proprietary computer software of Heverstow Limited of United Kingdom and Research Engineers. It has the ability to calculate and apply the wave loads on structures using Airy theory, Stokes 5th Order theory, and Stream function and transfer these loads to the STAAD Pro Software. Morison's Equations are used in the offshore software to calculate the wave force based on mass and inertia coefficients. In addition, Table 13 shows the input data used in Offshore Program Generator Software.

Simulating the design concept requires the use of two independent software packages: Offshore Program Generator (OPG) and STAAD Pro 2005. Output from STAAD Pro 2005 is fed to the OPG. The STAAD Pro output file is opened in the OPG environment for further coding and specifications other parameters. The final result of OPG is finally fed to STAAD Pro for final simulation. Because the two programs are independent software packages, they are not yet fully compatible. Thus, many compatibility bugs impeded our analysis efforts. The technical support and user manuals for both software packages do not offer any remedy for these interfacing bugs.

4.2 Overview of Test Cases

The structure is simulated in Staad Pro 2005 based on the scenarios and values indicated in Table 11. For the sake of simplicity, only some important elements were

Table 13 Offshore Loading Program Input Data for Airy, Stokes 5, and Stream 9 Theories

Wave Height	Wave period	Wave Direction	Wave Position – Step	Water Depth	Gravity Constant	Water Mass Density
6m	6s	0^o, 45^o, 90^o	(0,180) – 30	20m	9.81 m/s^2	1.025 ton/m^2

chosen to investigate the structure based on the maximum values of shears and moments in Fig. 30: node (415), circular columns (749 - 750), and beams (366 – 382– 486 – 487). Moreover, when the wave force is exerted and applied on the structure, different elements of compressions (red) and tensions (blue) in the beams and columns will emerge, as indicated in Fig. 31. In addition, Fig. 32 exhibits the different values of the global moments on the deck of the terminal, and it also indicates the location of the maximum value of the global moment, which is an important consideration for future design.

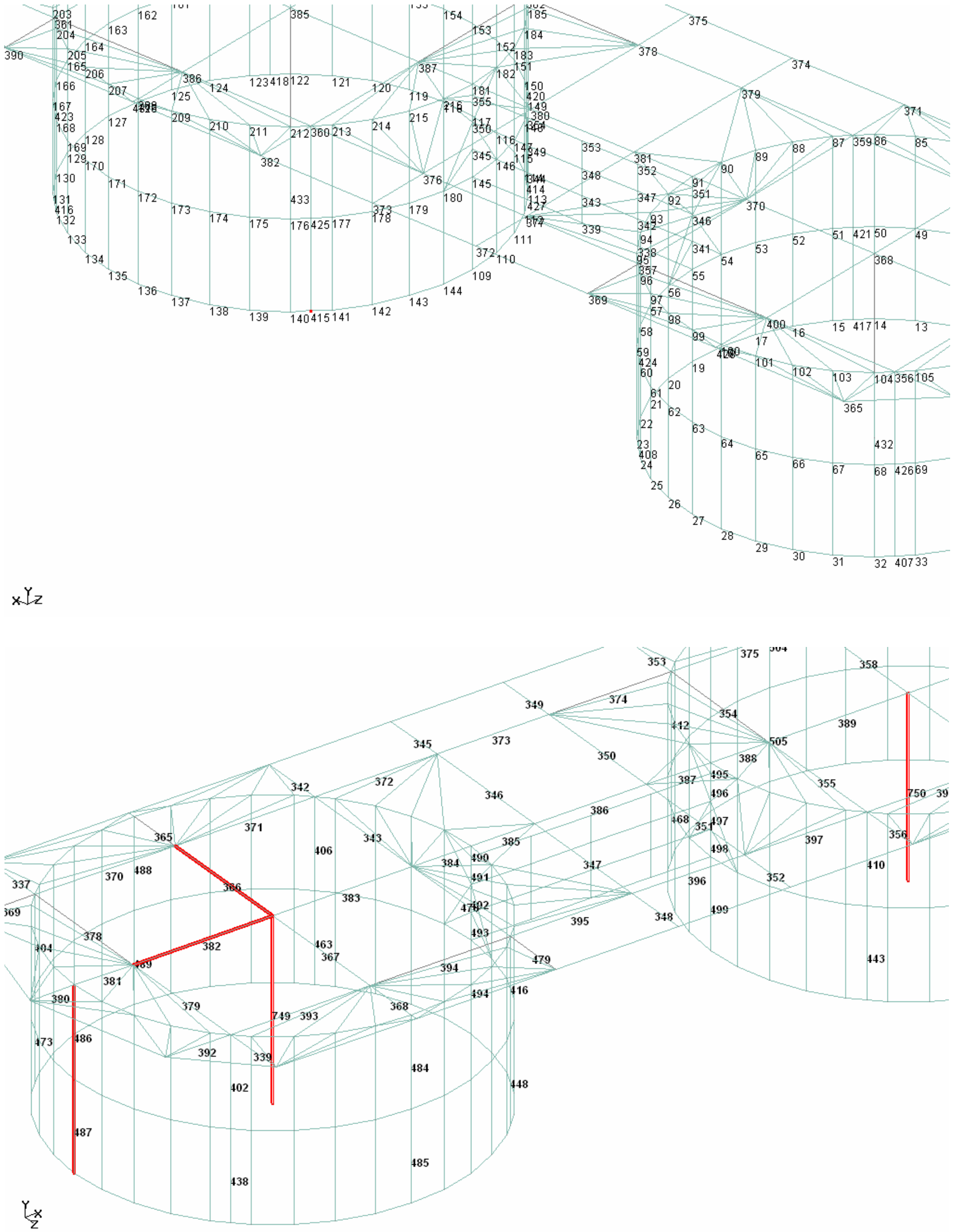


Fig. 30. Important Elements on the LNG Terminal Concept

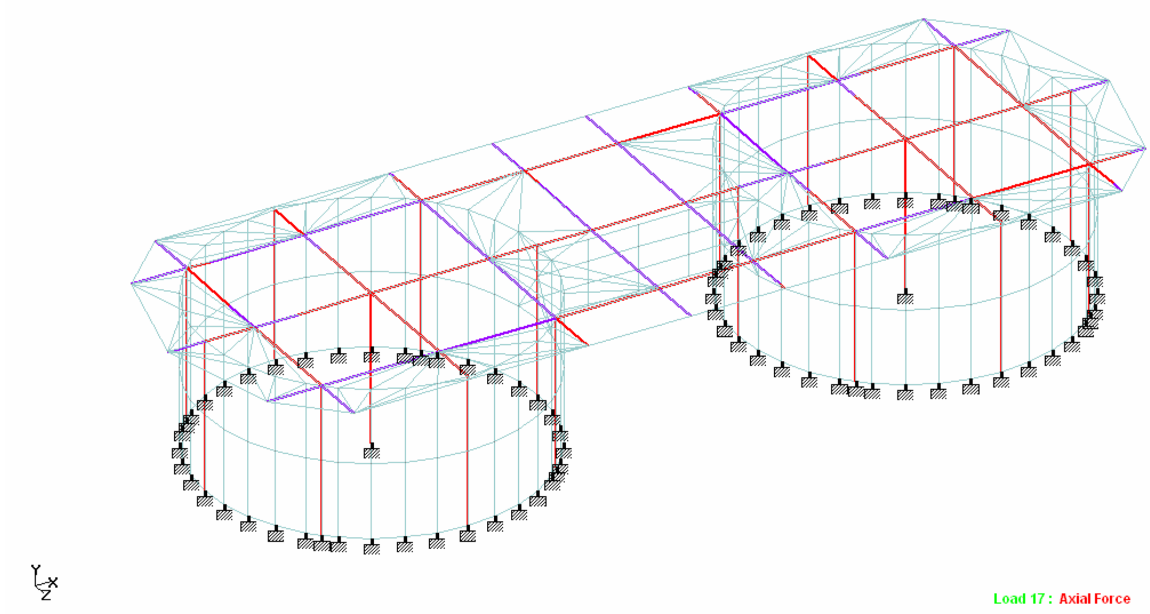


Fig. 31. Axial Force for the Whole Structure, Compression (red) and Tension (blue)

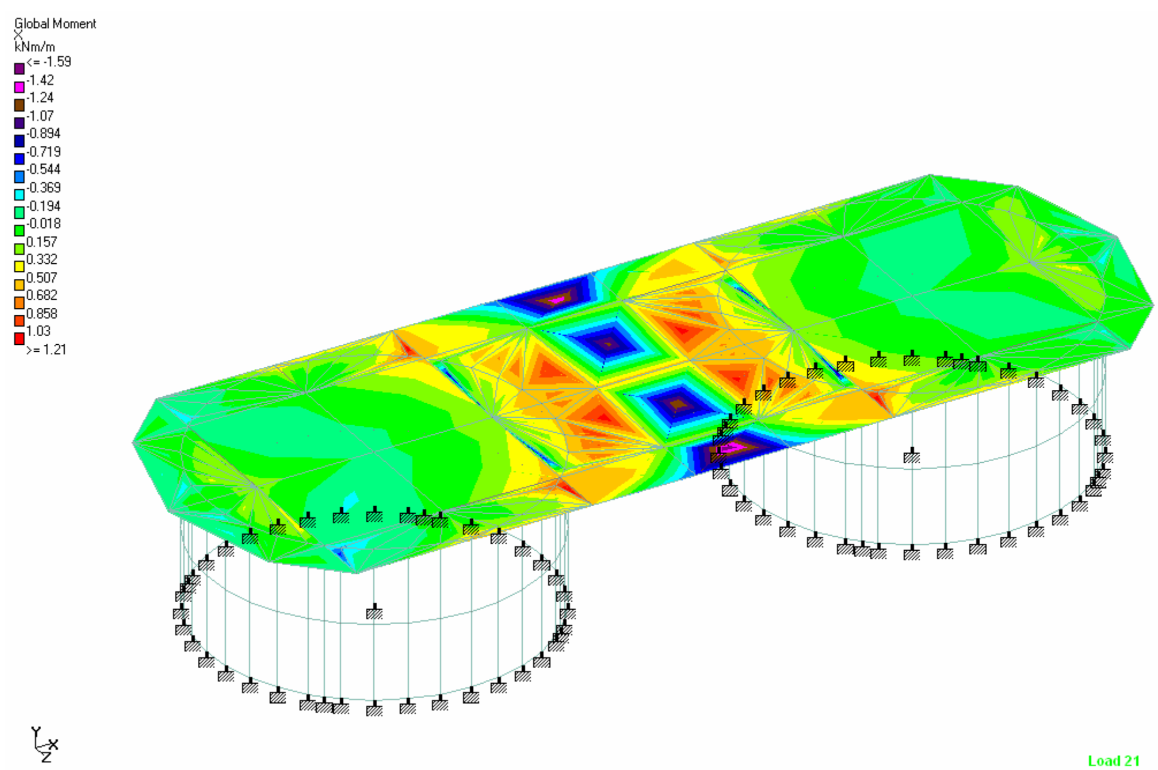


Fig. 32. The Global Moments on the Deck of the LNG Terminal Concept

Furthermore, Fig. 33 displays that value of the global moments on the vertical slab. For design considerations, we recommend to create holes on the vertical slab to reduce the force of the waves between the vessel and the terminal. In other words, by creating holes in the vertical slab, it will act as a wave absorber.

4.3 Interpretation of the Numerical Simulation

Node 415 is one of the nodes that have maximum values in Max Fx, Min Fz, Min Mx, and Min Mz. Figs (34-37) show the Max Fx, Min Fz, Min Mx, and Min Mz for node 415 in three tank levels (Empty, Half Full, Completely Full), two theories (Airy and Stream), and three wave directions (0, 45,and 90). The critical scenario will occur when the wave direction is at 45 degree. Compared with 0 and 90 degrees wave directions, the 45 degree direction has the maximum range and maximum value. However, for node 415 the maximum values for Min Fz and Min Mz will occur for the 90 degree wave direction, and this value is close to the 45 degree case.

Contrary to the values of the moment force, Figs (34-37) show that the values of the shear force is not significantly different under the empty, half full, and completely full tank levels. Also, the difference between the completely full and half full tank is bigger than the empty and half full tank. In addition, the value of the half full tank level is always between empty and completely full tank levels, and this finding supports our design choices and decisions. Furthermore, the stream function has more steepness than Airy especially in the 45 and 90 degrees. Figs (38-41) show an insignificant difference between Stokes and Stream for the same node 415. From theses figures, it seems that the Stream Function is steeper than the Stokes.

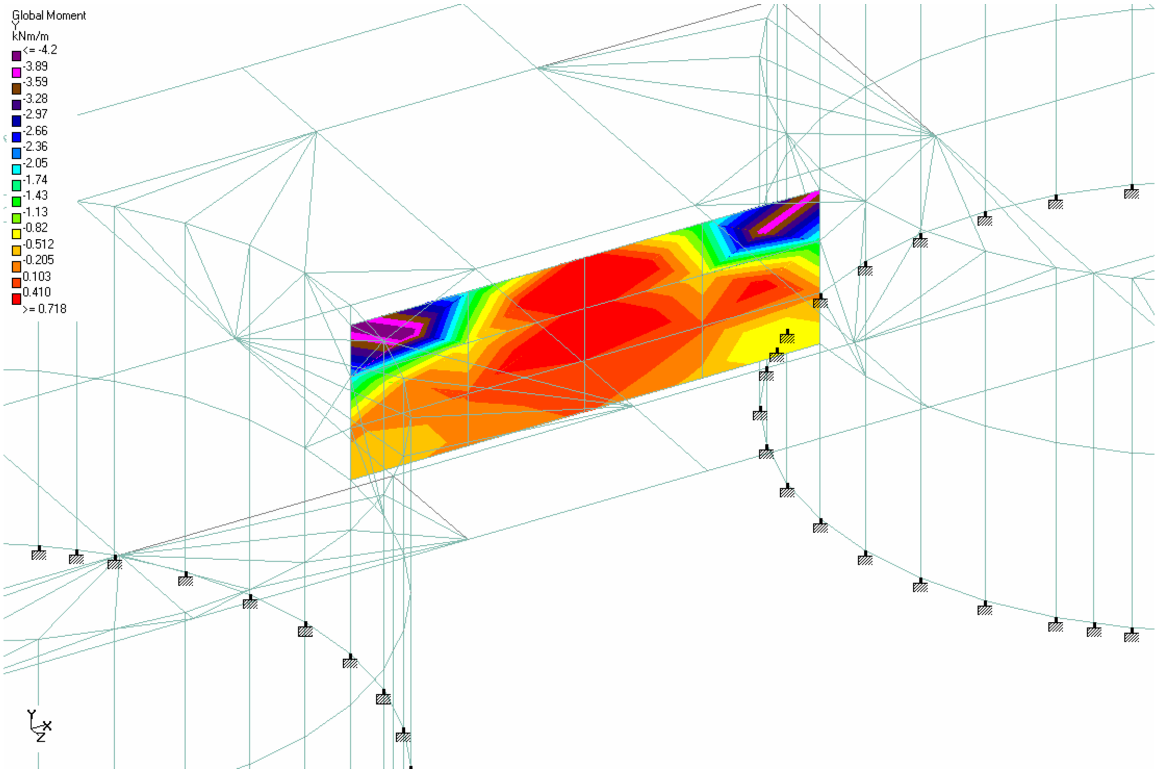
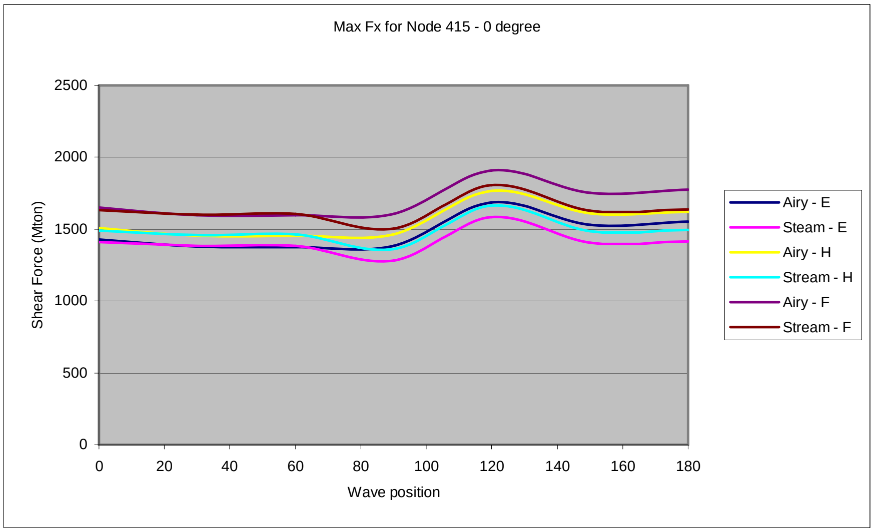
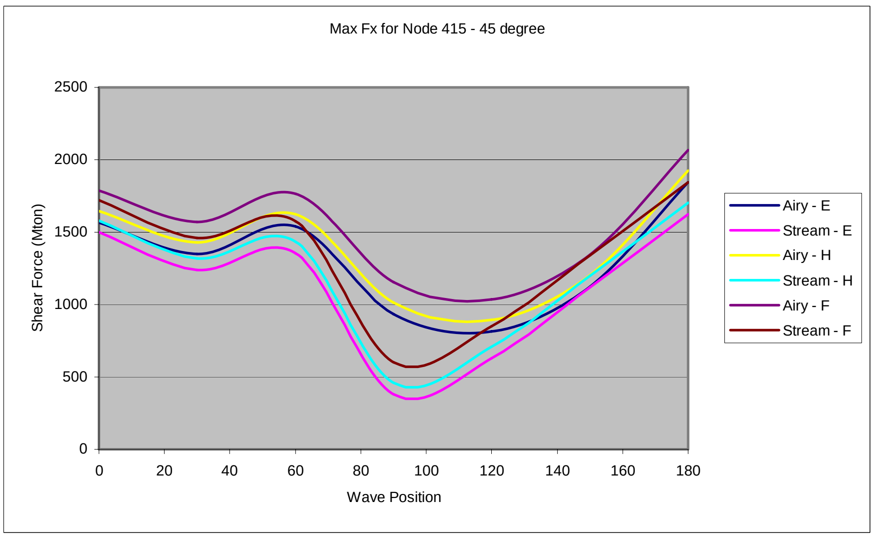


Fig. 33. The Global Moments on the Vertical Slab Between the Two Tanks.





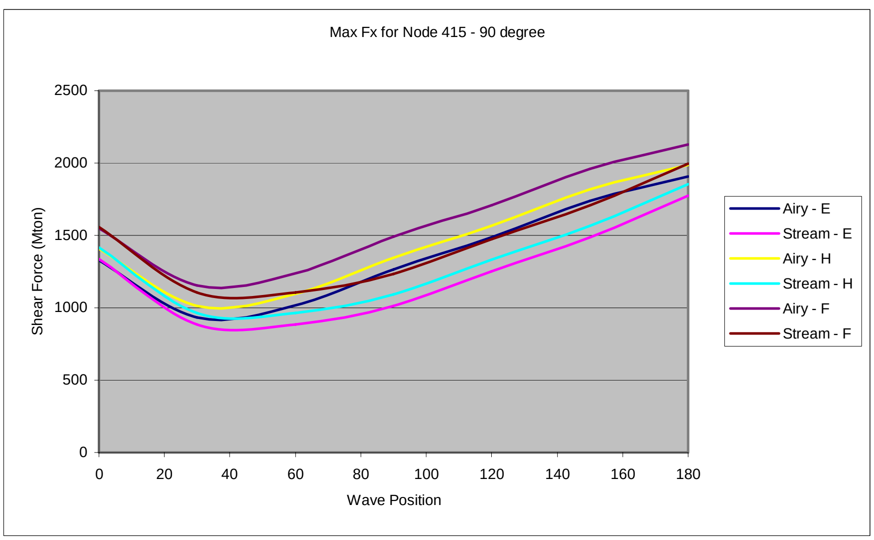


Fig. 34. Max Fx for Node 415 (Airy vs Stream)

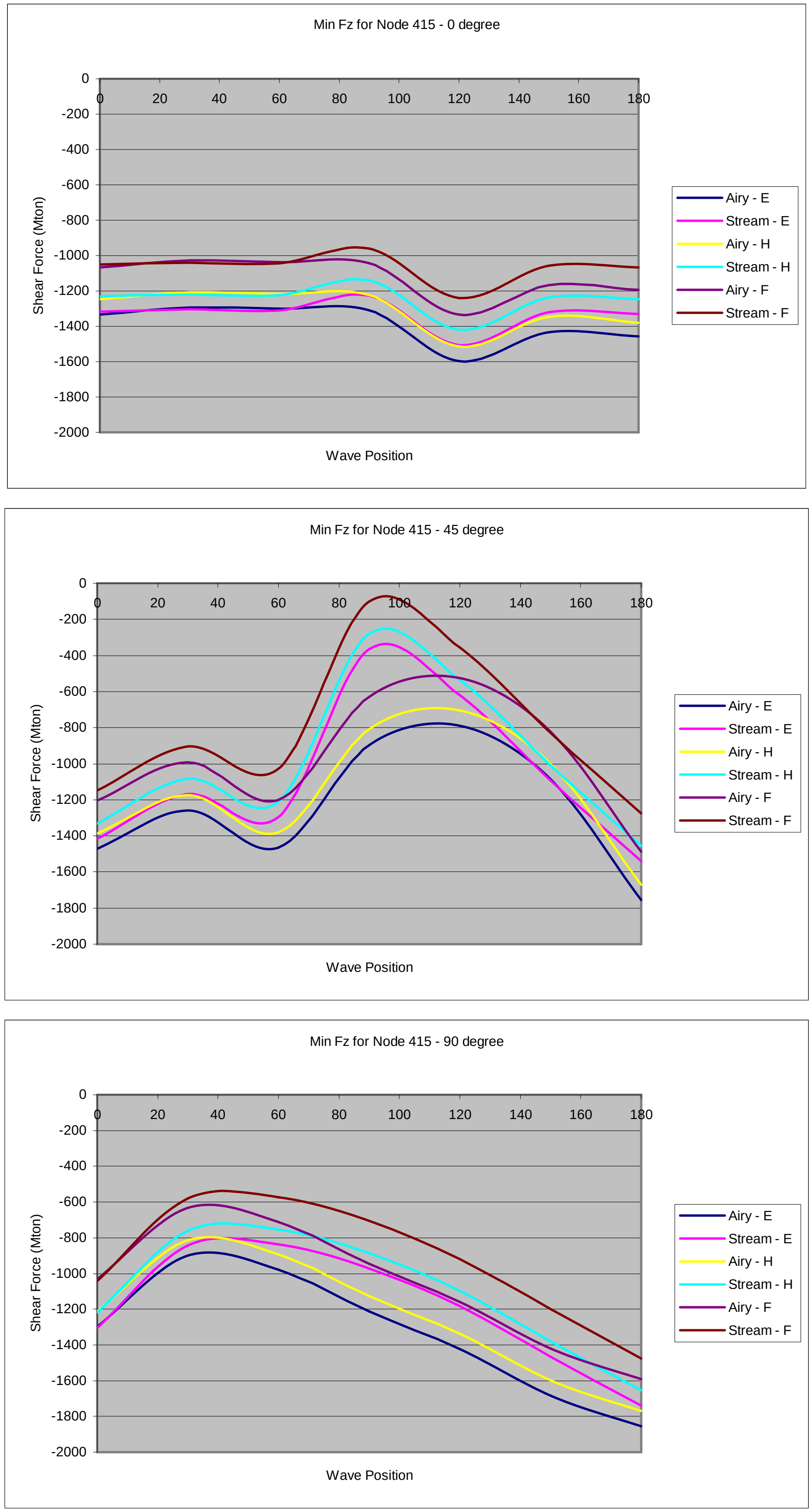
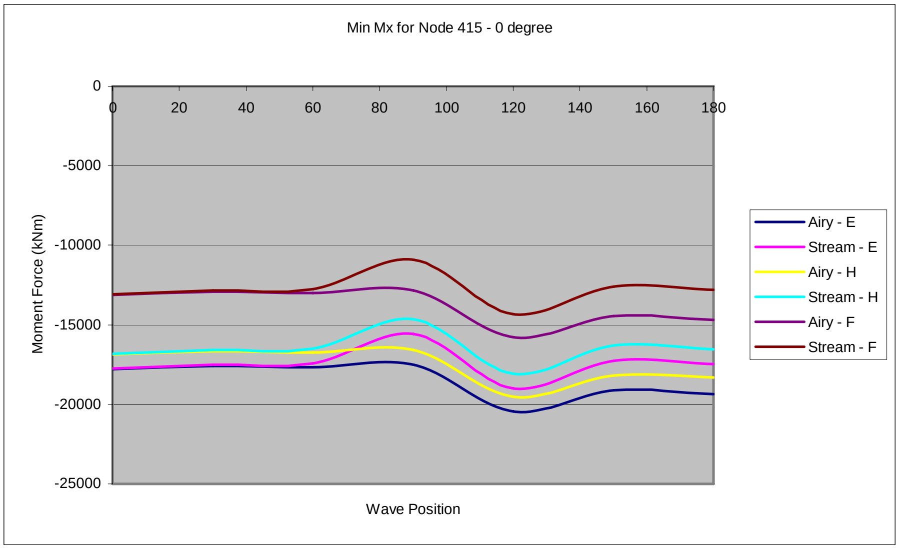
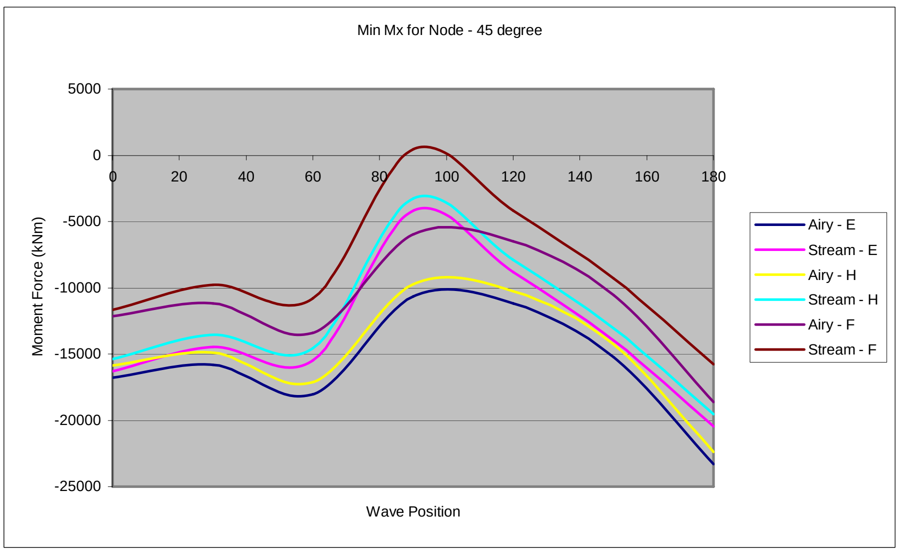


Fig. 35. Min Fz for Node 415 (Airy vs Stream)





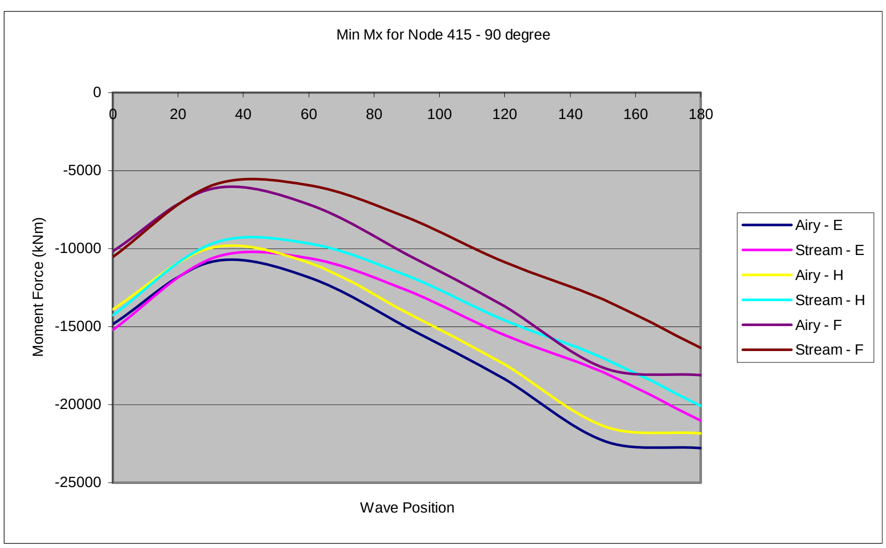
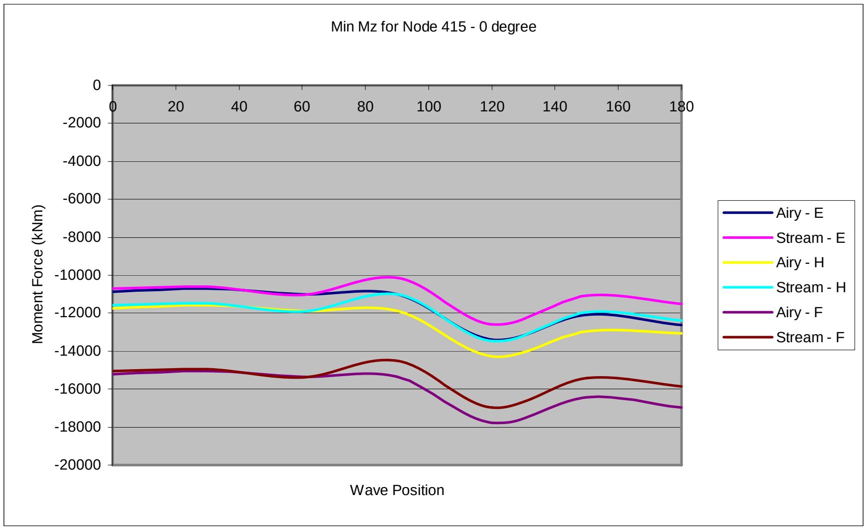
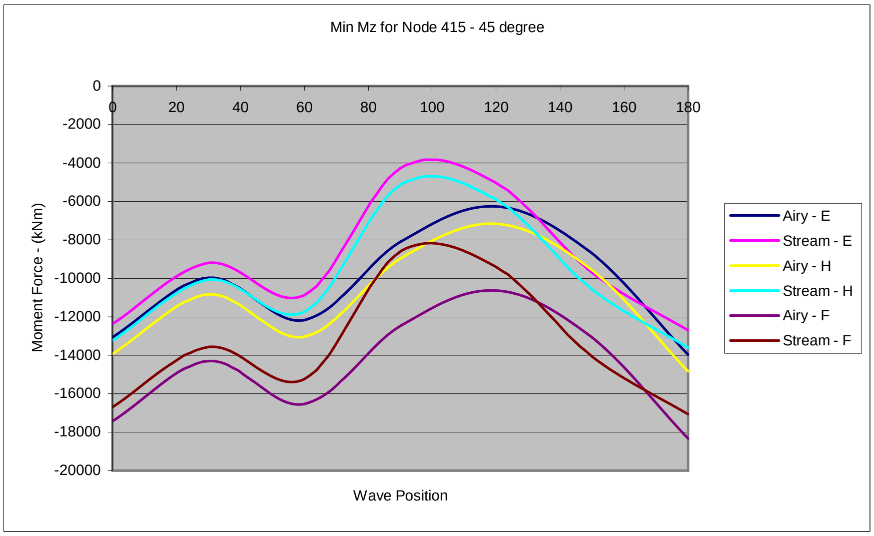


Fig. 36. Min Mx for Node 415 (Airy vs Stream)





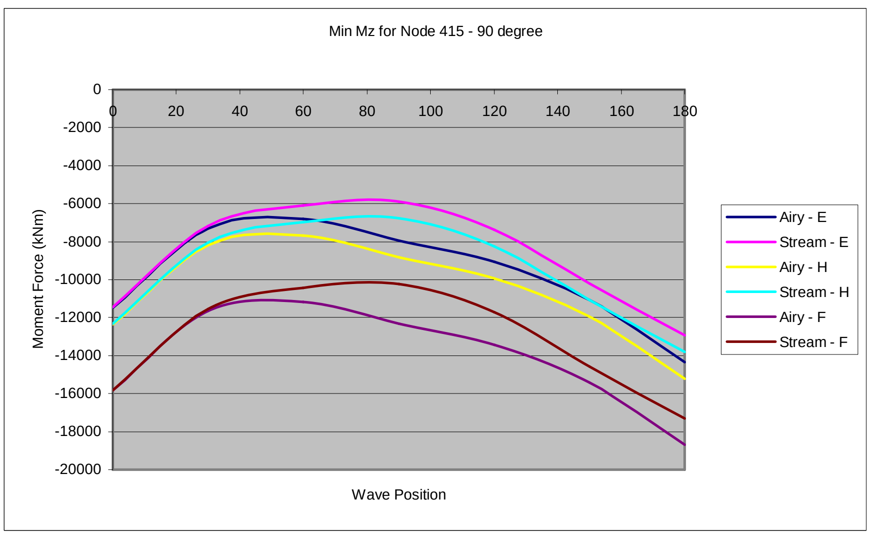
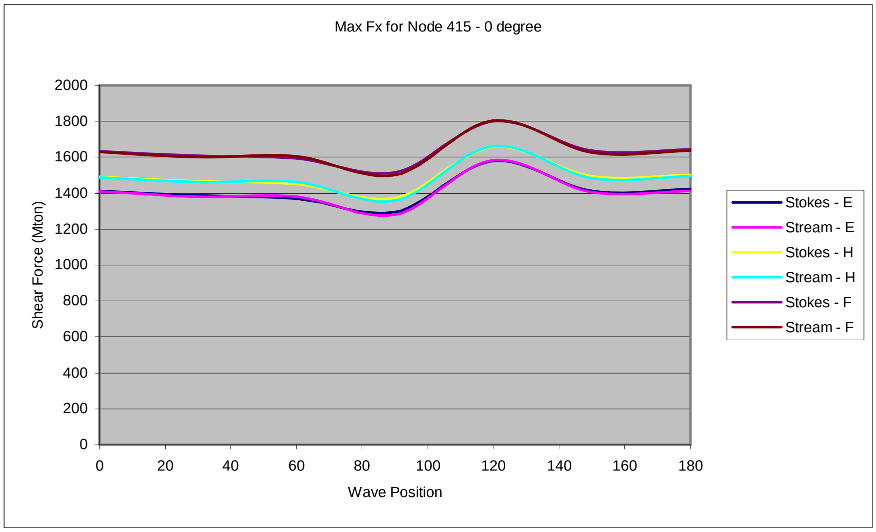
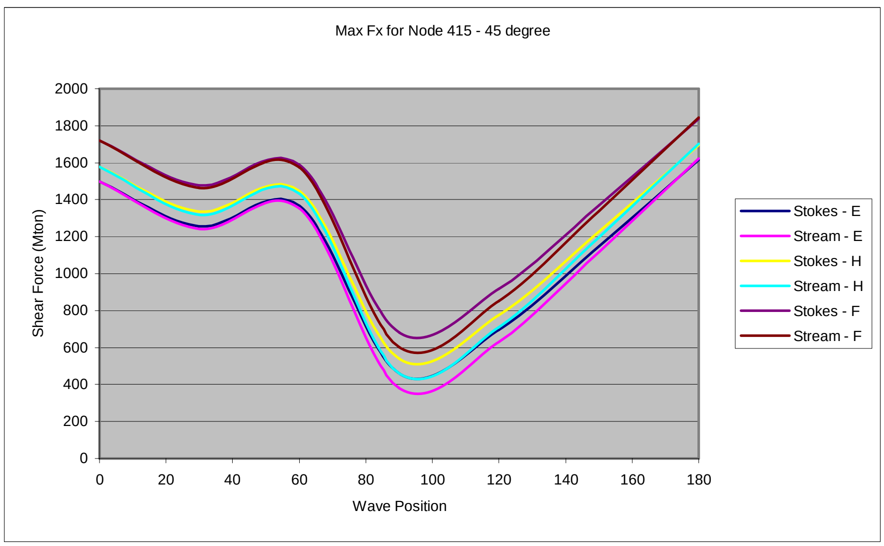


Fig. 37. Min Mz for Node 415 (Airy vs Stream)





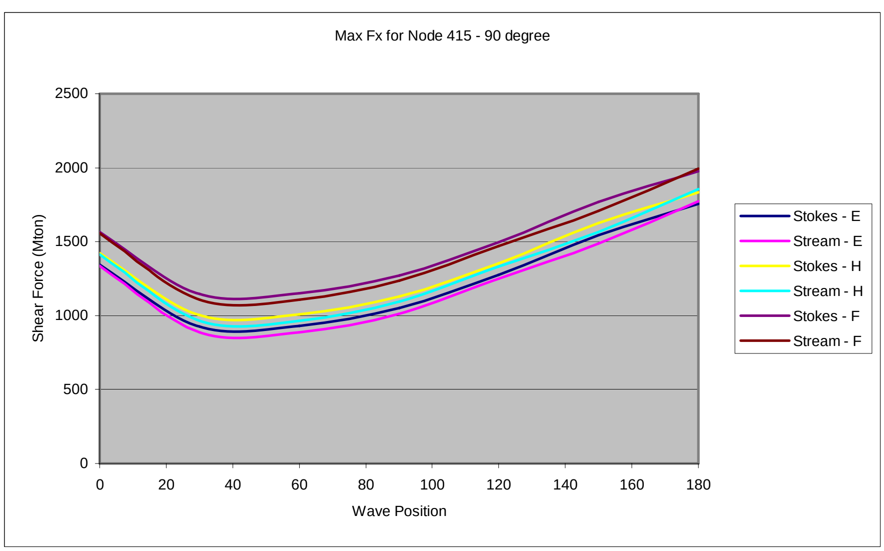


Fig. 38. Max Fx for Node 415 (Stokes vs Stream)

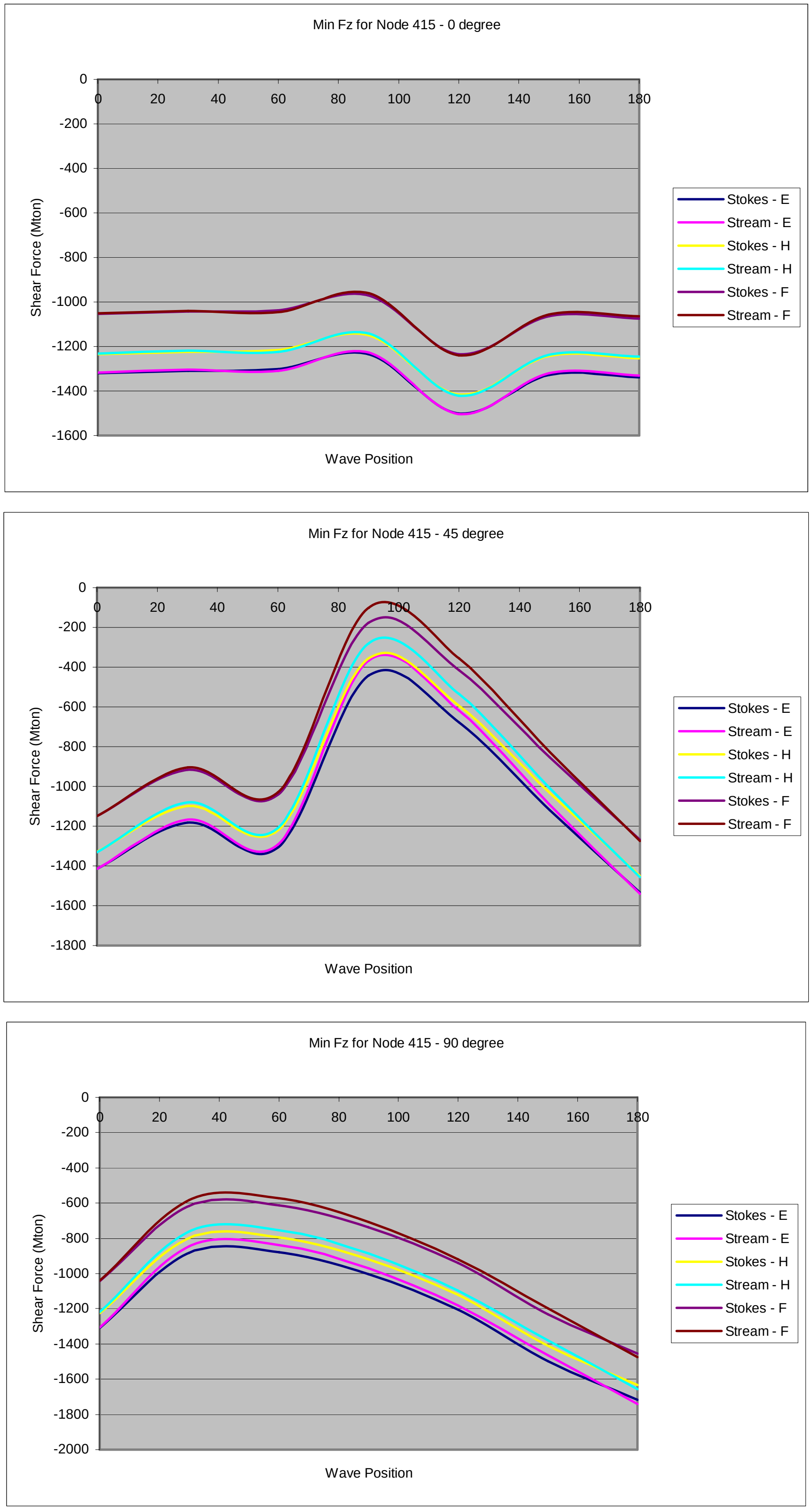


Fig. 39. Min Fz for Node 415 (Stokes vs Stream)

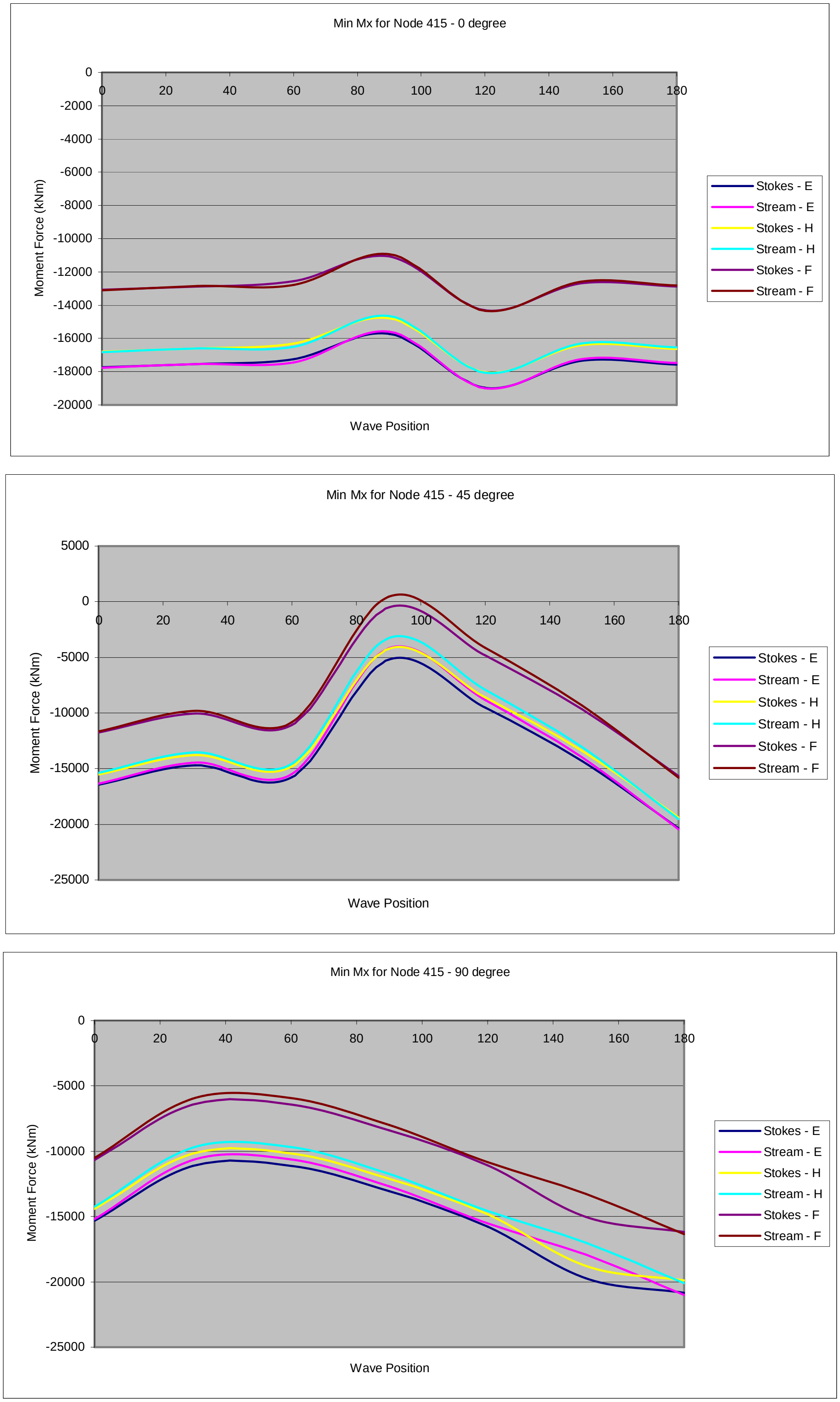


Fig. 40. Min Mx for Node 415 (Stokes vs Stream)

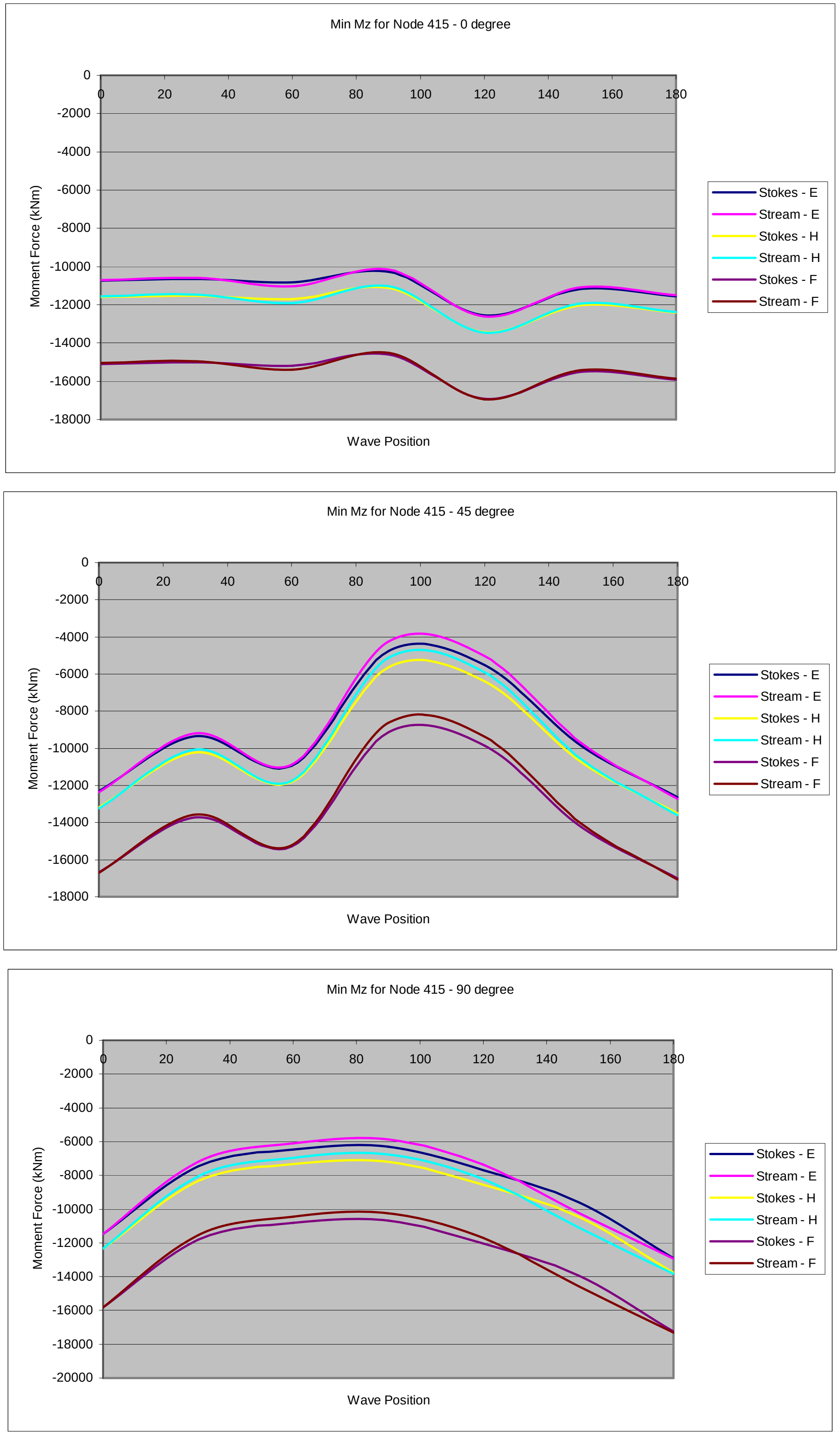


Fig. 41. Min Mz for Node 415 (Stokes vs Stream)

According to Figs (42-43), circular columns (749 – 750) that are in the middle of each tank have an enormous axial force value. The critical scenario is on Airy 45 degree for both columns, which have the maximum value and range for axial force compared with 0 and 90 degrees. There are three important comments for these scenarios. First, the empty, half full, and completely full tank levels do not affect the axial force on these columns. Second, in 90 degree case according to Figs (749 – 90 degree, and 750 – 90 degree), the direction of the applied wave will be the same on both column 749 and column 750, thus, both columns will experience the same wave force. Third, consistent with our theoretical expectation, the simulation results indicate that in 0 degree the 749 column has greater maximum value and range compared to the 750 column. As alluded to, this was expected because the wave will impact the first tank that houses column 749, and this will decrease the effect (impact) of the waves on the second tank which houses column 750. Figs 44 and 45 display the maximum Mz (+ve & -ve) of the horizontal beams (366 – 382) under the previously indicated scenarios. Similar to the above discussion regarding columns 749 and 750, the maximum values of Mz (+ve & -ve) for beams 366 and 382 are insignificantly different for the three tank levels (empty, half full, and completely full).

Moreover, the critical scenario (i.e., maximum value and range) for beams 366 and 382 based on Fig. 44 and 45 is in 45 degree case. However, the maximum range of Mz (+ve) for beam 366 is in the 90 degree case. With respect to the vertical beams of the structure, vertical beam 486 has the maximum value of Mz (-ve) in 45 degree and maximum range in 0 degree as shown in Fig. 46. On the other hand, according to Fig 47, the maximum value and range of Mz (+ve) for vertical beam 487 has almost the same effect results for the 0, 45, and 90 degrees cases.

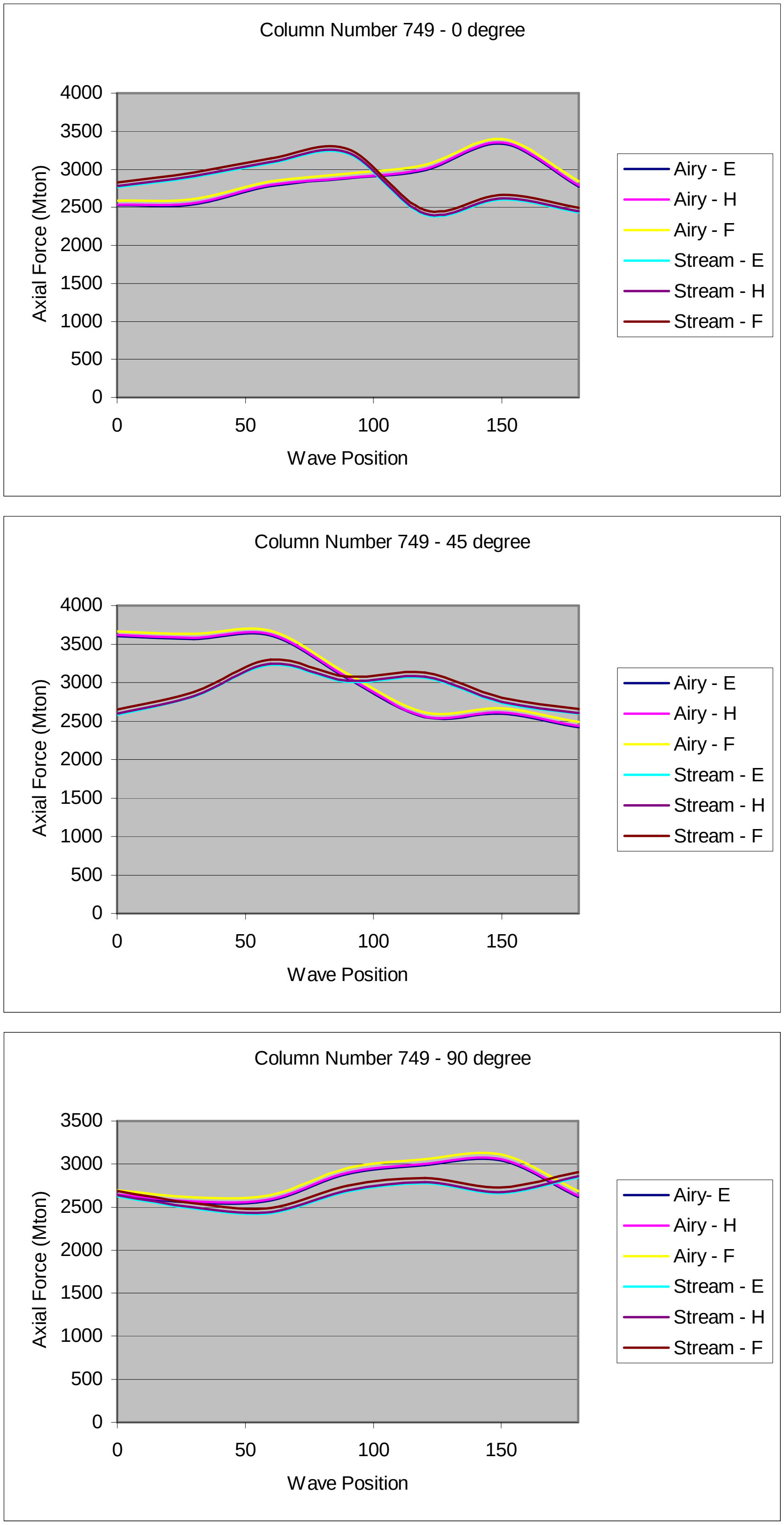


Fig. 42. Axial Force for Column Number 749 (Airy vs Stream)

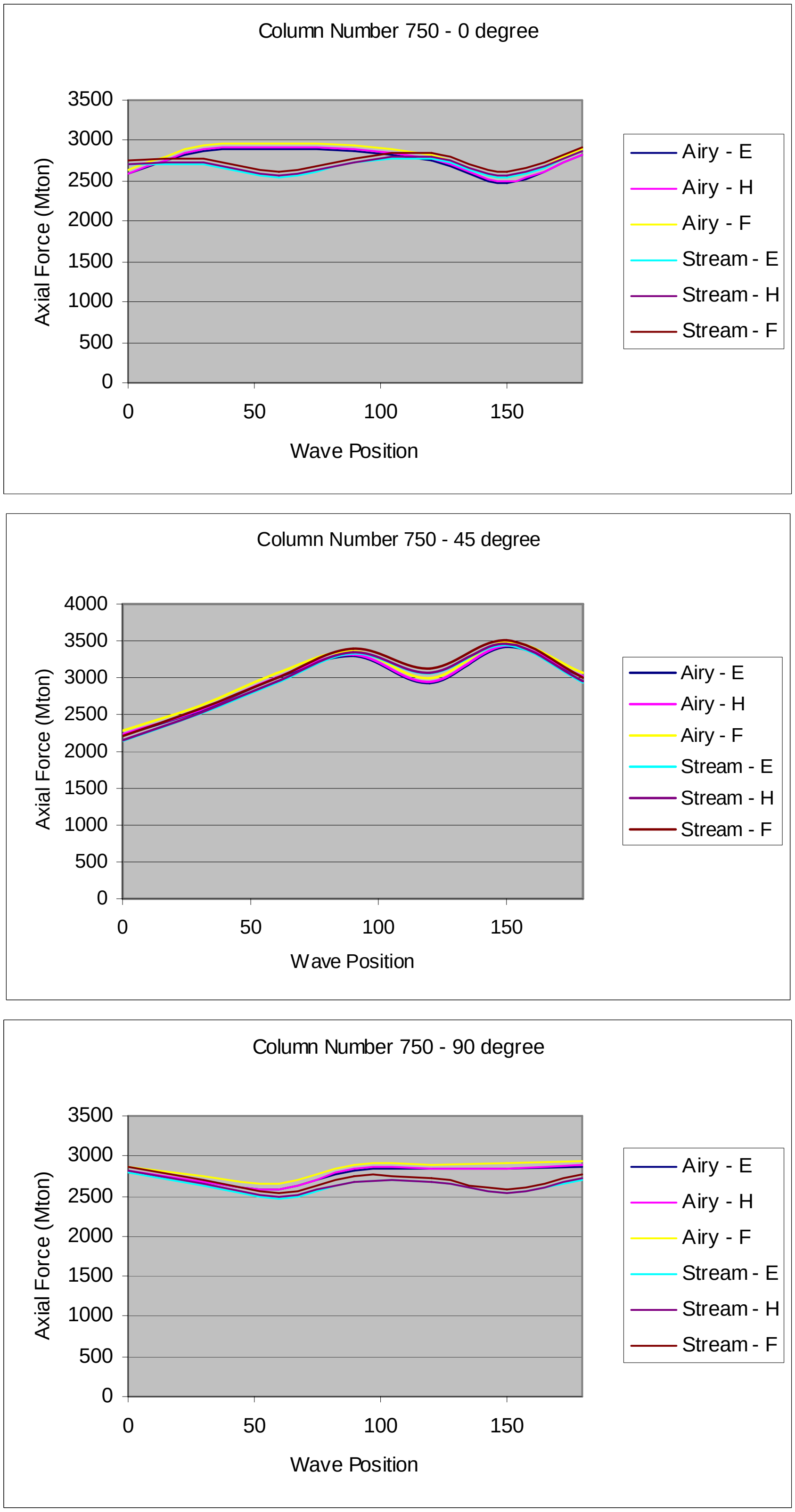
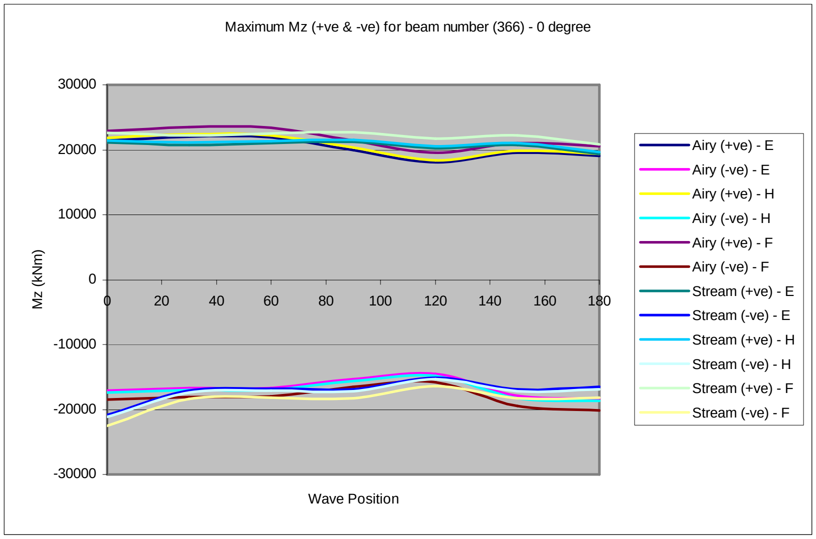
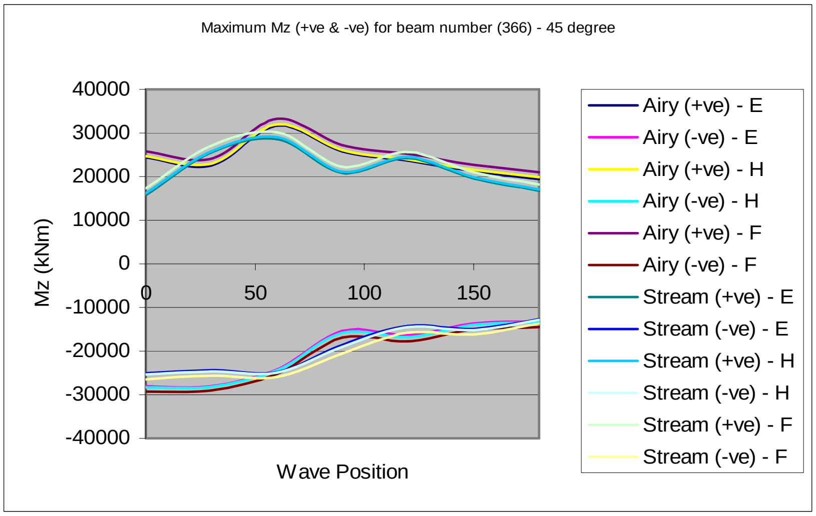


Fig. 43. Axial Force for Column Number 750 (Airy vs Stream)





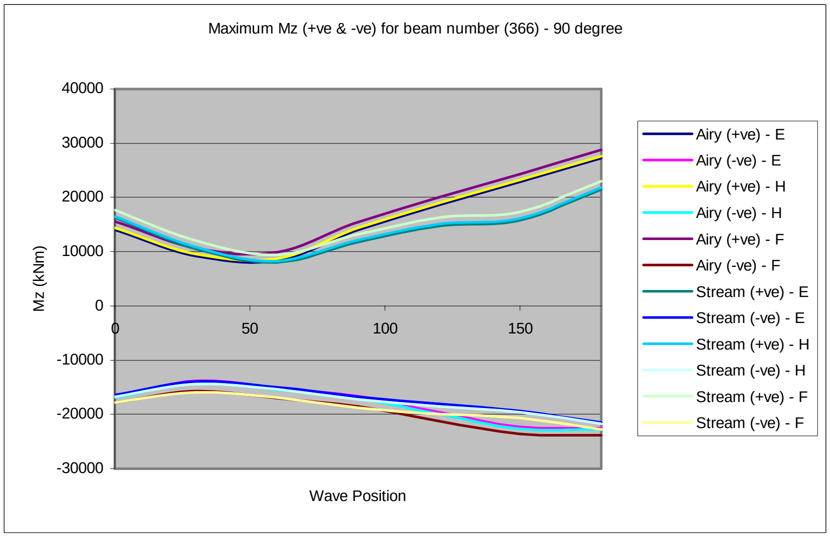
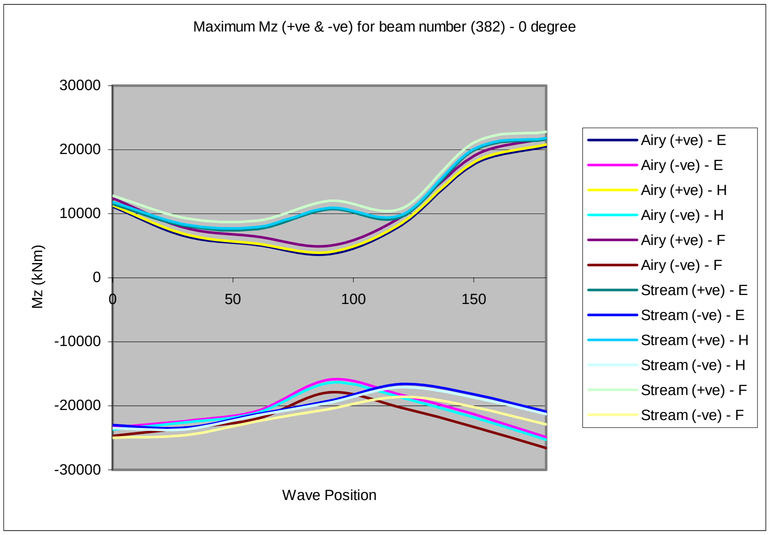
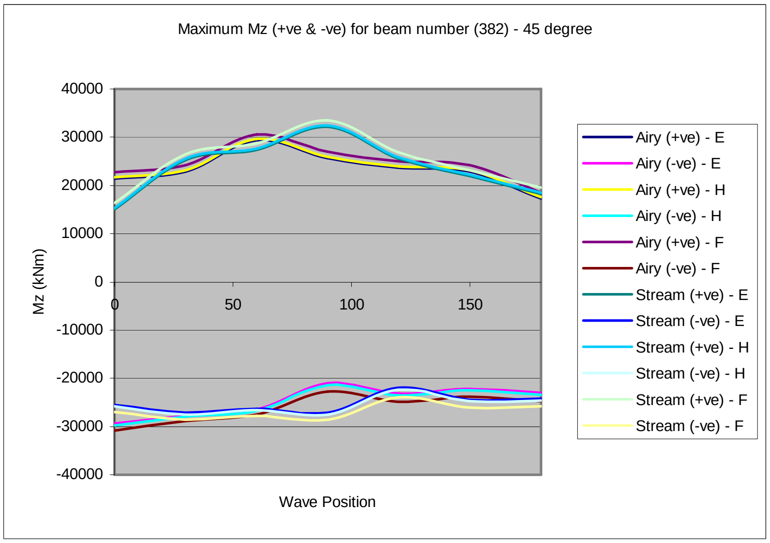


Fig. 44. The Maximum Mz (+ve & -ve) for 366





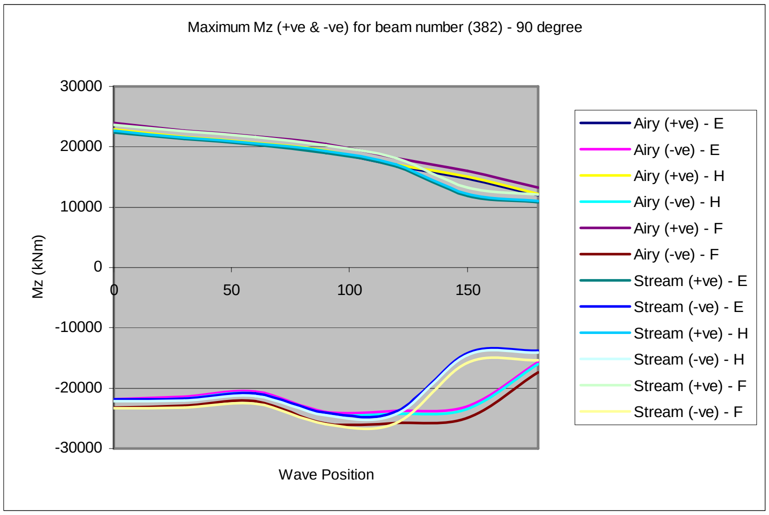


Fig. 45. The Maximum Mz (+ve & -ve) for 382

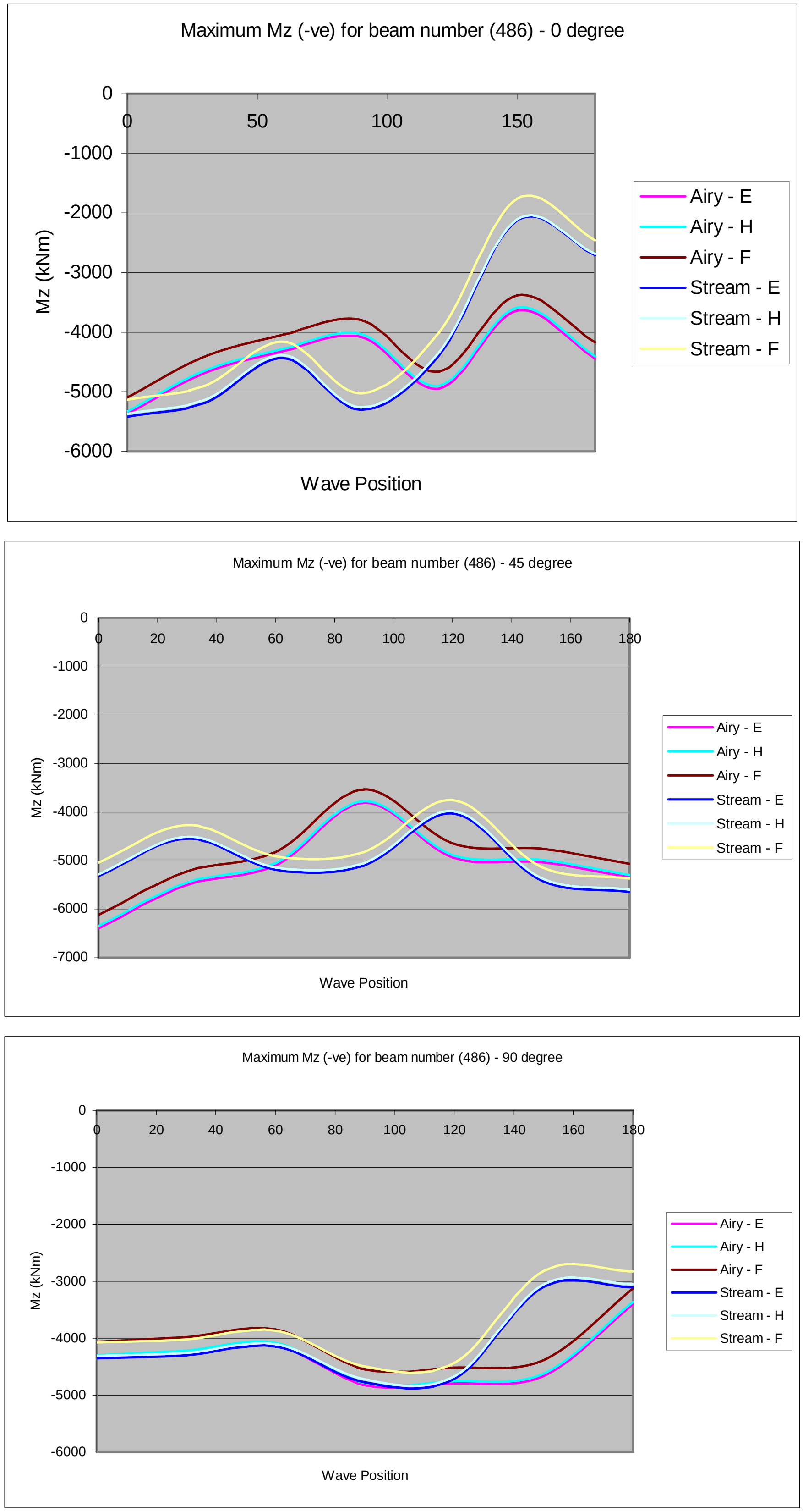


Fig. 46. The Maximum Mz (-ve) for 486

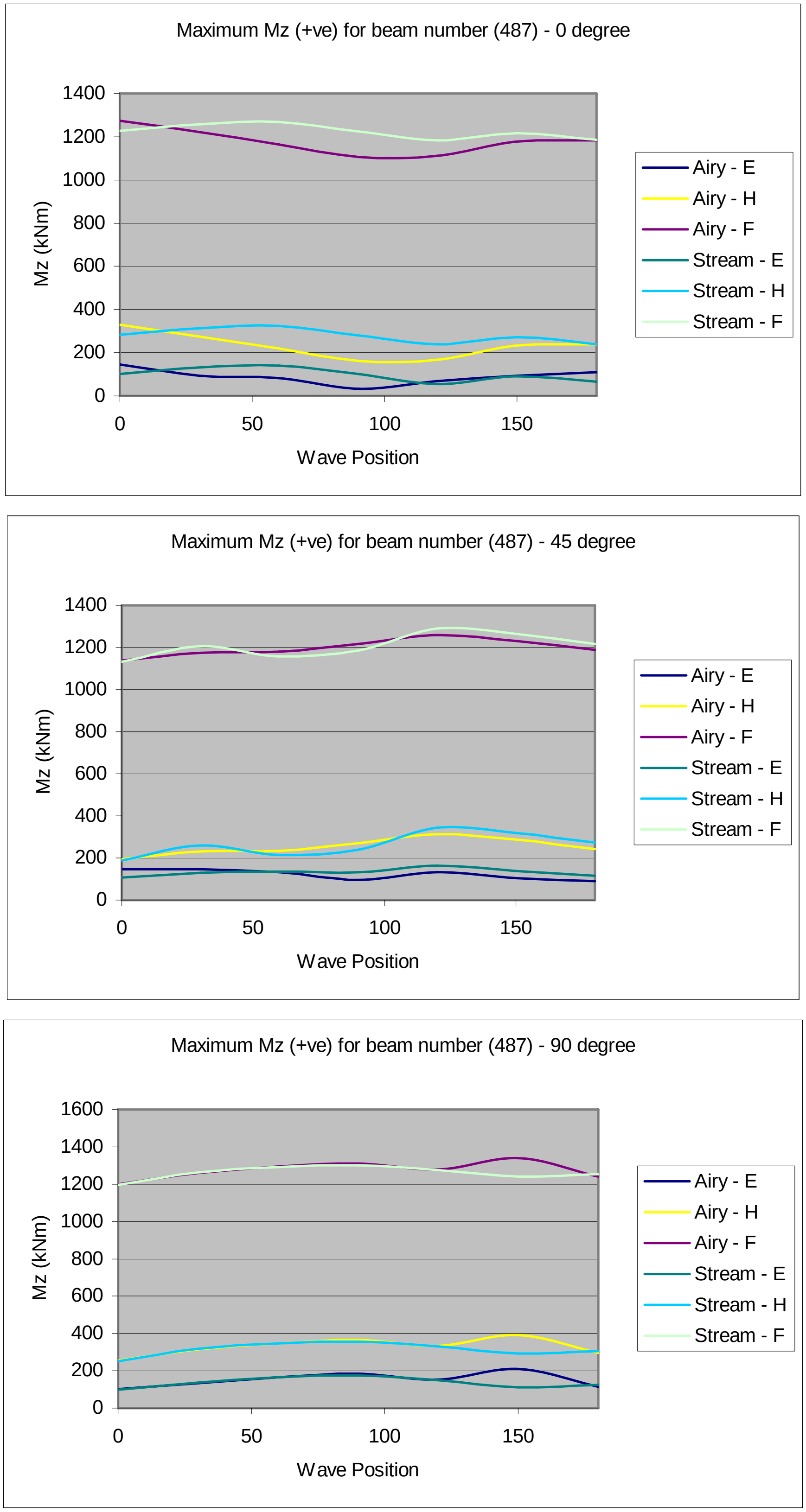


Fig. 47. The Maximum Mz (+ve) for 487

Comments: as indicated in Fig. 46, the Mz (-ve) of vertical beam 486 is significantly greater in absolute value than the Mz (+ve) of vertical beam 487. For the two vertical beams 486 and 487, the gap between the Full and Half full tank levels is greater than that between the Empty and Half full tank levels.

Another comment is regarding the contour map of the global moment in Fig (32). This contour map is for the Airy 45 degree case, and it indicates the distribution of the positive (+ve) and the negative (-ve) moments for the entire deck. The distribution of the moments that is indicated for the Airy 45 degree case resulted form two factors. First, there is no underlying support for the deck to account for the span between the two tanks. Second, the liquefaction facility is located at approximately the center of the deck, and thus exerting the maximum moment as indicated in the contour map. The contour map of the global moments for the vertical slap is indicated in Fig (33). According to the displayed distribution of the moments, the two maximum negative moments occur on the upper left and right edges of the vertical slap. Finally, Fig (31) is a display of the axial forces of beams and columns. In this Fig, the columns and vertical beams always indicate compressions, while the horizontal beams indicates compression (red) or tension (blue) depending on the direction and position of the wave.

4.4 Foundation Design

According to the previous information, we know that the soil is clay and our calculations indicate that the embedment depth for the shallow foundation, based on this equation

$$q_{ult} = N_c S_u + \gamma D_f \quad (4)$$

will be very high ($D_{embedment} \geq 10m$). Based on this, pile foundation is one of the best options to consider for the new concept design in order to go a little bit further on the foundation stage with clay soil. Fig.48 indicates the total strength of the clay soil versus the embedment depth of pile, according to Steel Open-ended Tube Piles Equation

$$Q_{Total} = Q_{Side} + Q_{Tip} = \alpha S_{uAVG} A_P + S_u N_c A \quad (5)$$

Based on Fig. 48, the embedment depth of our concept will go 85 ft for 8 piles with diameter 8 ft. However, we will go with 100 ft, because of the settlement that we did not include.

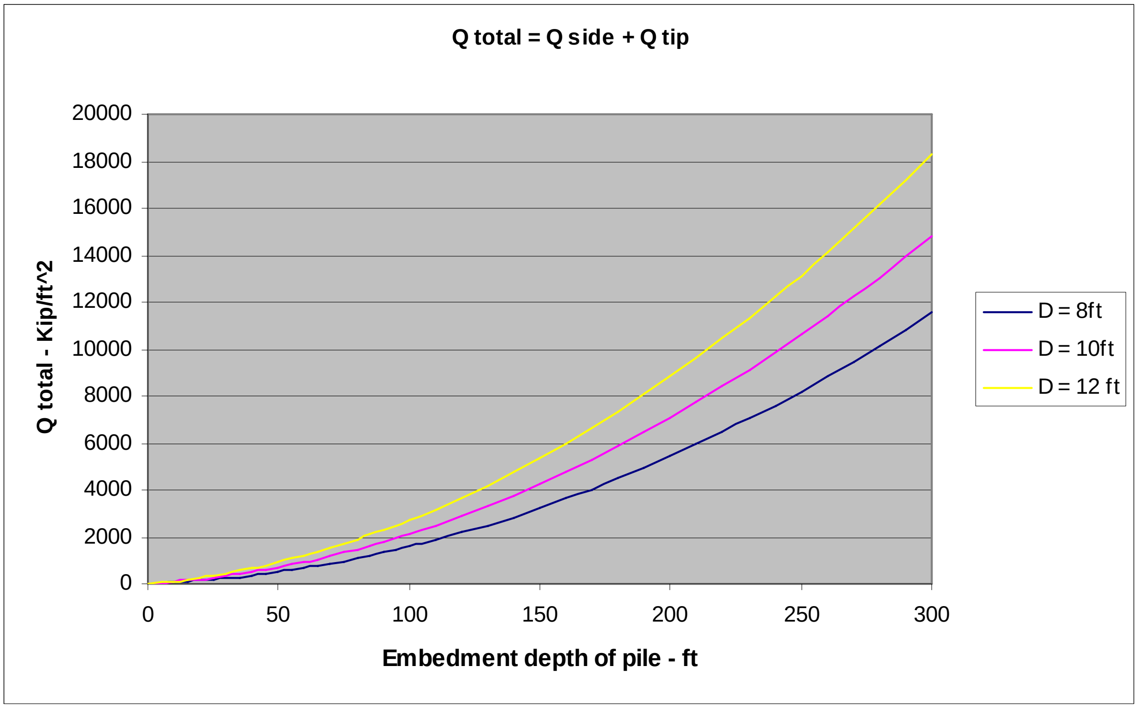


Fig. 48. Total Strength of the Clay Soil

5. SUMMARY AND CONCLUSION

The revenue from the oil industry is the primary source of the national income in Kuwait. The government of Kuwait has always been concerned with this fact given the turbulent nature of the oil industry. Thus, the government of Kuwait has been always exploring other possibilities to diversify its sources of income. Experts in the energy market report that the world's demand for natural gas is projected to continue to increases and this fact is an incentive for Kuwait to explore this arena. Kuwait has considerable reserves of natural gas that are not yet fully exploited and the current reserves are not yet used to full capacity. Compared to the oil industry, the natural gas sector is considered is considered to be in its early stages of develop. At this time there is a noticeable lack of design concepts and readily available expertise to address the expected growth of the natural gas industry in Kuwait. This report sheds some light on a range of currently existing designs and capabilities that are available as a starting point. This report is a first attempt to develop a new design concept tailored for an offshore natural gas terminal that is tailored to the geographical terrain and offshore environmental conditions for Kuwait. The proposed design concept needs a lot more scrutiny in order to be sufficiently developed as a concept where it can be confirmed as a truly viable concept and investment. This report also tackles some preliminary issues that are adequate for an initial evaluation of the proposed design concept.

A modified gravity based system (GBS) was suggested and then analyzed using a state-of-the-art Finite Element Analysis software package STAAD Pro 2005 and its accompanying module, the Offshore Program Generator, to develop the wave loading based upon a user specified design wave and a Morison wave force formulation. The

STAAD Pro 2005 software is an industrial strength software package that provides an automatic check of the appropriated design code for steel or concrete structures and more about the software can be found on the web. The software version that was used limits the application to 500 elements but it is capable of identifying critical elements in the structure. This served as the basis for selecting the data that was presented on maximum shear and moment. The design wave conditions were based upon data reported along the from the Kuwait coastline, and was adjusted to reflect reasonable design practice. The design waves were modeled using Airy (linear), Stokes V and Deans's Stream Function wave theories. The effect of the variation of the flow kinematic models was illustrated in the graphs on shear and moment information. As a consequence of this analysis it was determined that a pile foundation appears to be the best option for this LNG terminal design concept. A flowchart presenting a schematic of the this research activity is presented in Fig. 49.

The following points stem from the simulation and analysis of the different loading scenarios that were conducted in this research study. It was confirmed that quartering sea conditions, waves approaching as a 45 degree angle, is the most critical scenarios for the terminal based on maximum values and ranges of shears and moments. In addition, moment values have very large ranges compared with shear values. Interestingly, for this design concept the main concern in this concept will be the moment failure and not the shear failure. It was also determined that the deck experiences maximum moments (+ve & -ve) at the center along with the short direction of the deck. The empty, half full, and completely full tank levels do not noticeably affect the axial force on the circular columns but of course this will impact the foundation design. The vertical beams that surround

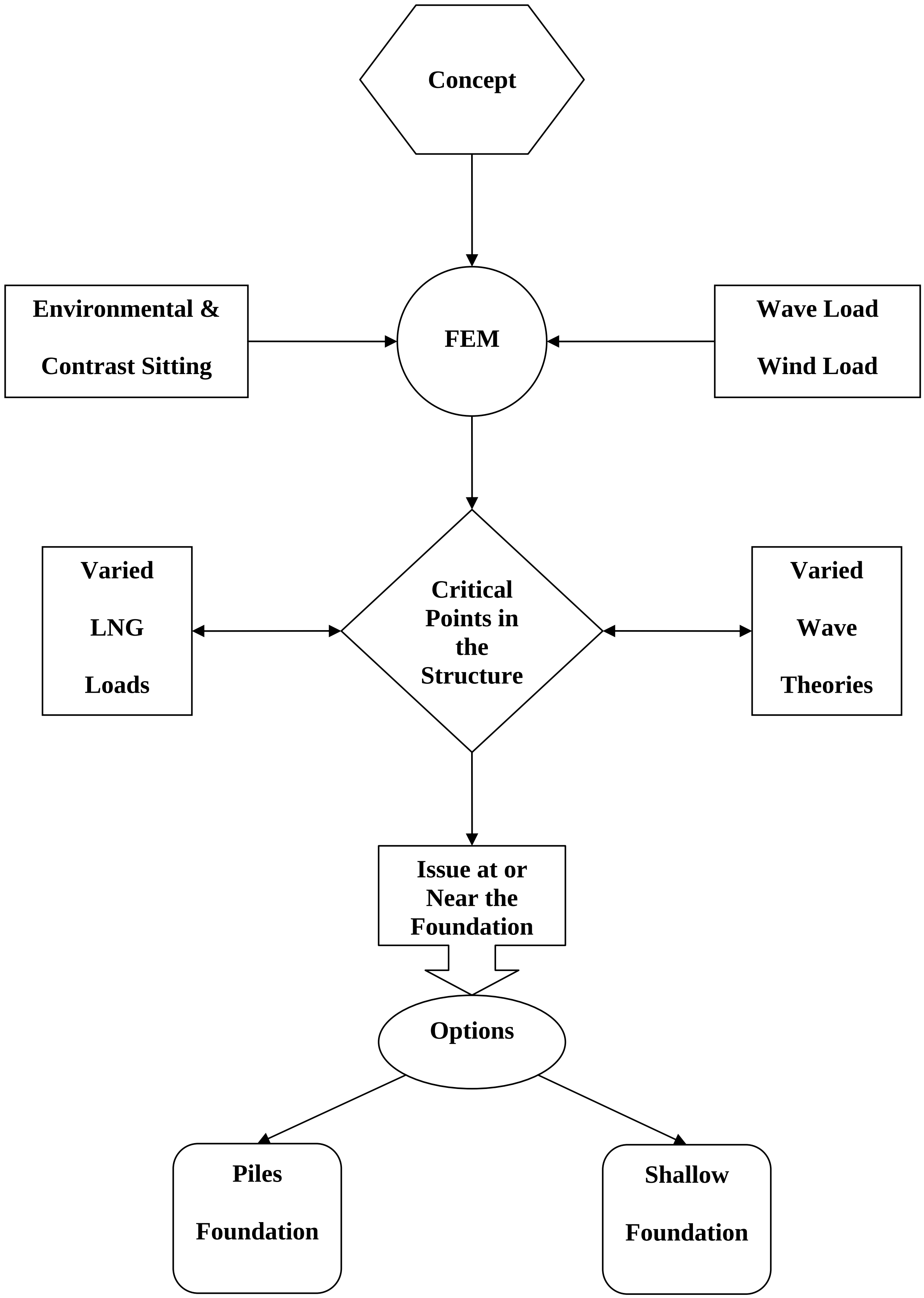


Fig. 49. Summary

each tank have significant values of (-ve) moments for the upper half of the beam, and this requires further study in the future. The vertical slab between the two tanks has maximum negative moments that occur on the upper left and right edges.

In addition to these findings there are several interesting issues in this concept that should be further looked at for as this design is further developed. For example the horizontal beams that hold the deck need further attention especially in the middle strip area of the deck which has the maximum moments. Additional aspects that were not addressed in this research such as currents, air and sea temperature ranges, soil settlement, and basement slab of the tank need to be investigated. It is recommended that in future studies one should consider perforating the vertical slab, perhaps with circular holes, in order to reduce the force of the waves between the vessel and the terminal to serve as a wave absorber.

Clearly, there is a need for more data suited for improving design estimation based on geological perspective and every effort should be made to search historical records including for example the proceedings of the Royal Society. Information on earthquakes, sandstorms and other extreme environmental conditions need to be identified and addressed in the design process. The wave force model was only used to obtain rough numbers and is not adequate for use in the next stage of design, as the LNG terminal really falls into the classification of large body hydrodynamics which requires nonlinear diffraction-radiation computations and the addressing of multi-body hydrodynamics interactions. Thus, although this study was a first step in developing an LNG terminal design for Kuwait, a lot more effort is required will be required to establish this concept as suitable design that is complementary to the existing infrastructure and can provide a good return on investment for the country.

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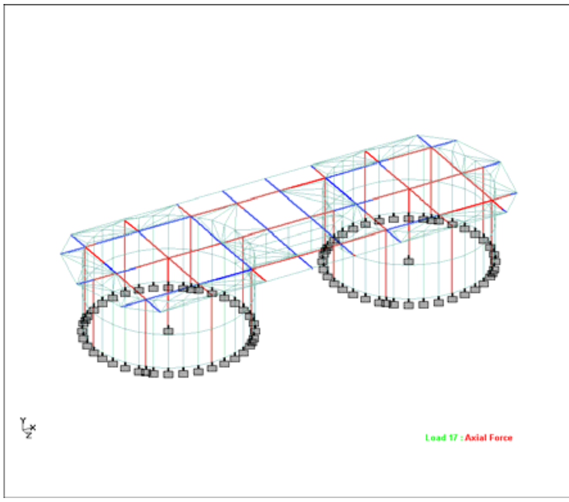
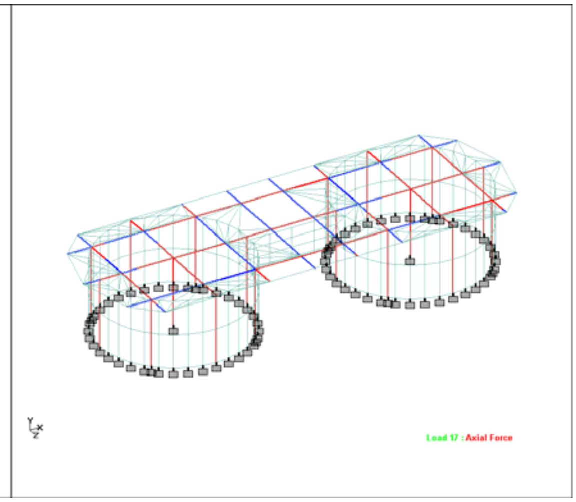
APPENDIX

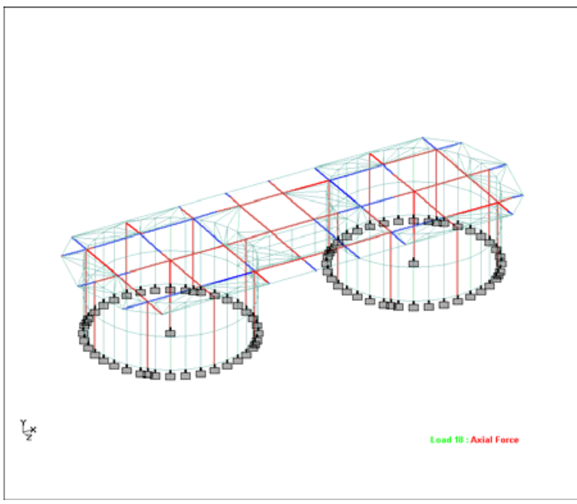
This appendix presents a comparison (by figures) between Airy and Stream in 45 and 90 degrees, wave position from 0 to 180 with interval 30, and empty tanks for the all scenarios. These figures are focused on axial forces (compression [red color] and tension [blue color]), maximum moments on the vertical slab, and maximum moments on the deck.



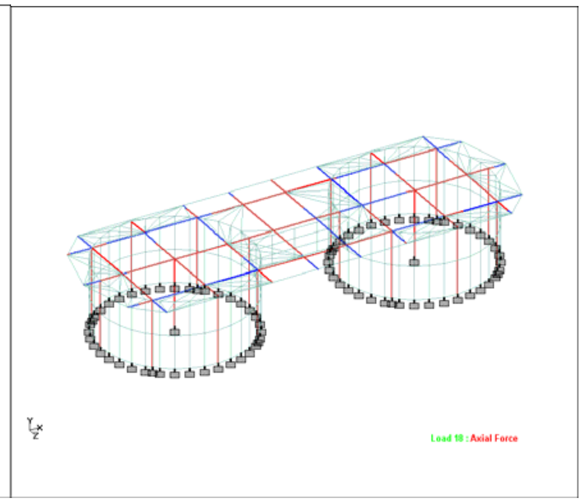
Airy (45 degree - 0 wave position)



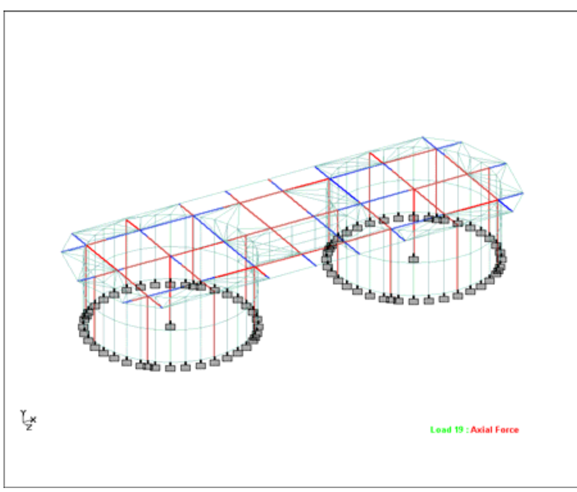
Stream (45 degree - 0 wave position)



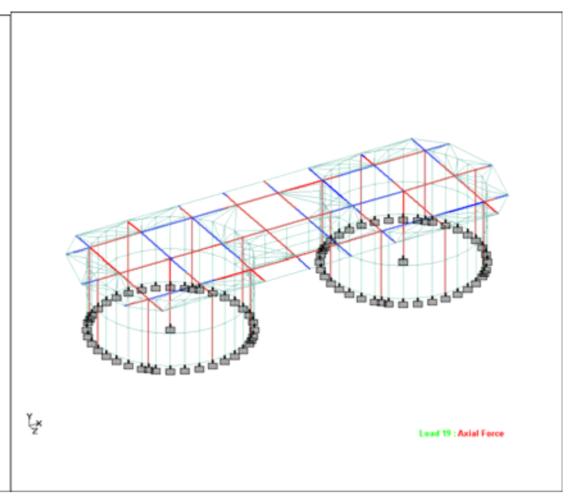
Airy (45 degree -30 wave position)



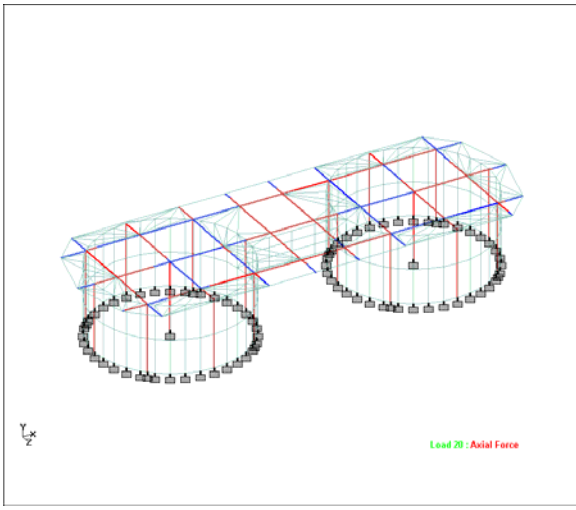
Stream (45 degree - 30 wave position)



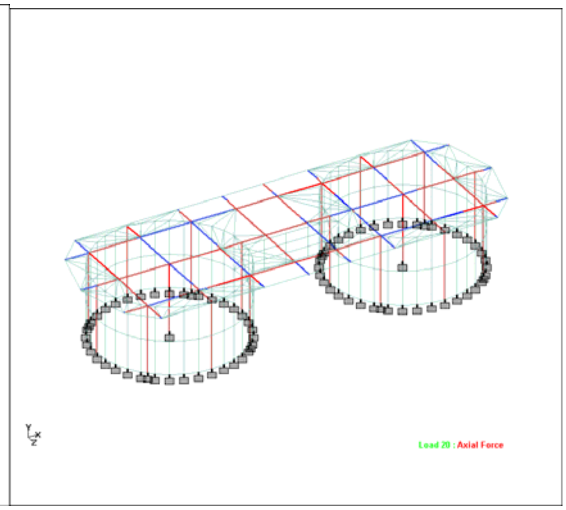
Airy (45 degree - 60 wave position)



Stream (45 degree - 60 wave position)



Airy (45 degree - 90 wave position)



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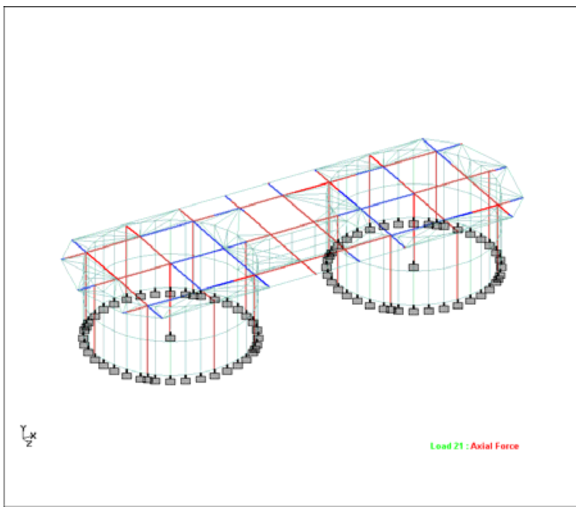
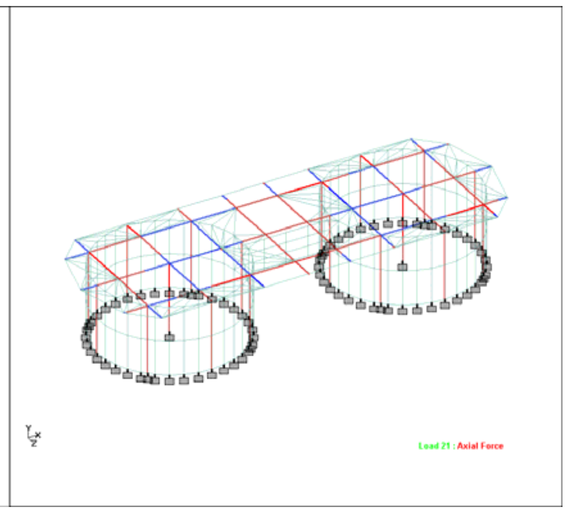
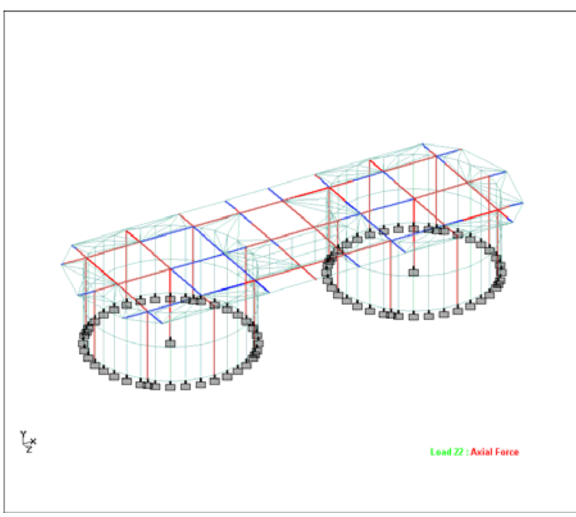


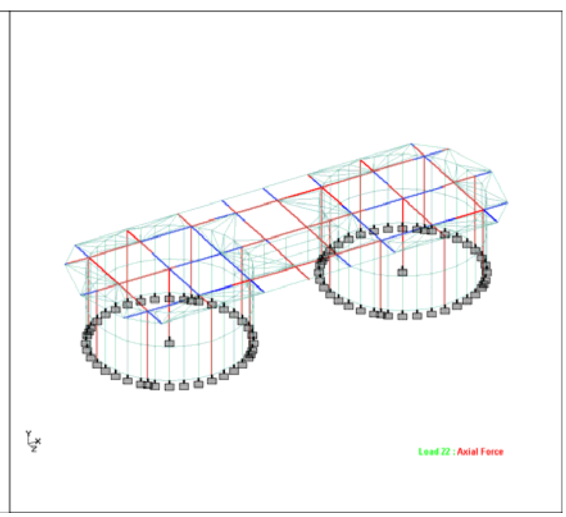
Airy (45 degree - 120 wave position)



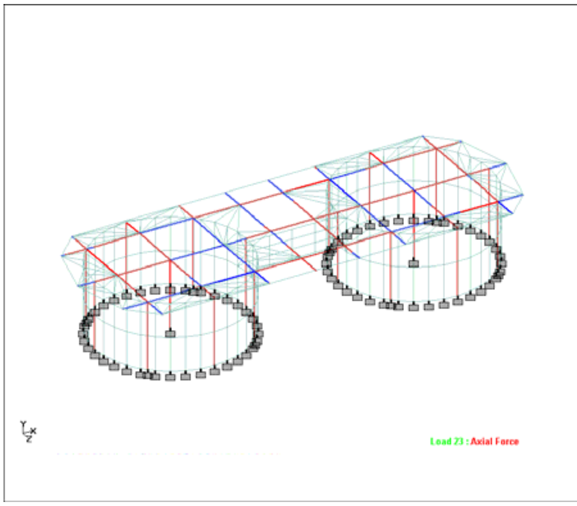
Stream (45 degree - 120 wave position)



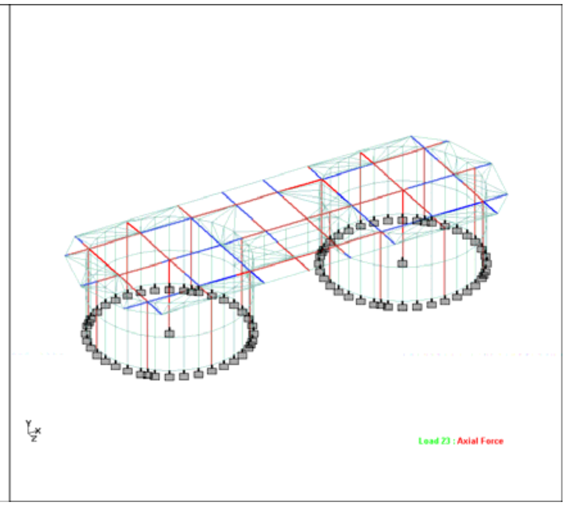
Airy (45 degree - 150 wave position)



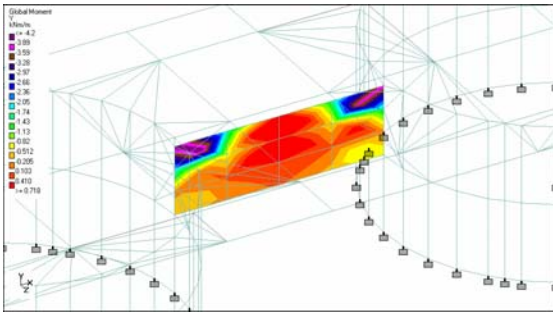
Stream (45 degree - 150 wave position)



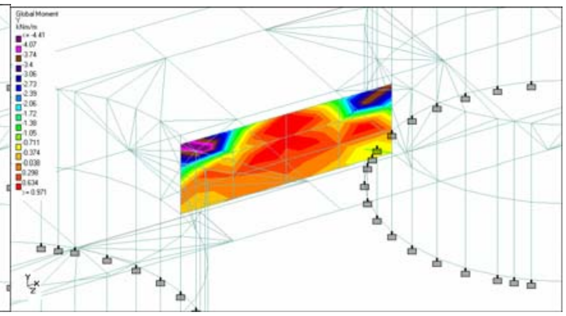
Airy (45 degree - 180 wave position)



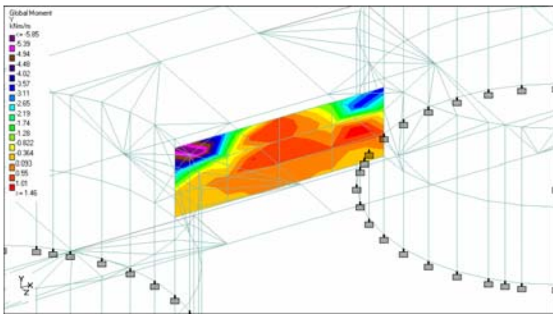
Stream (45 degree - 180 wave position)



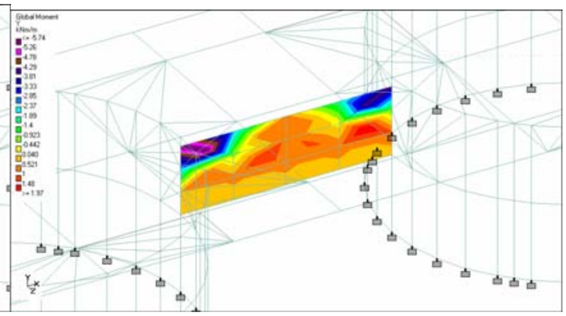
Airy (45 degree - 0 wave position)



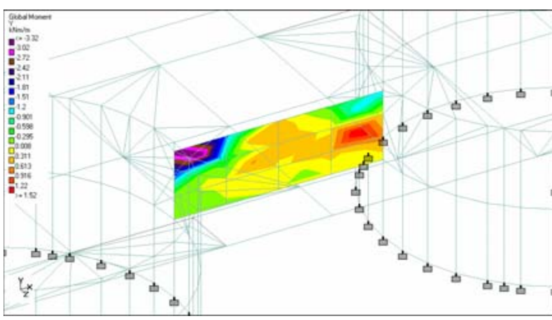
Stream (45 degree - 0 wave position)



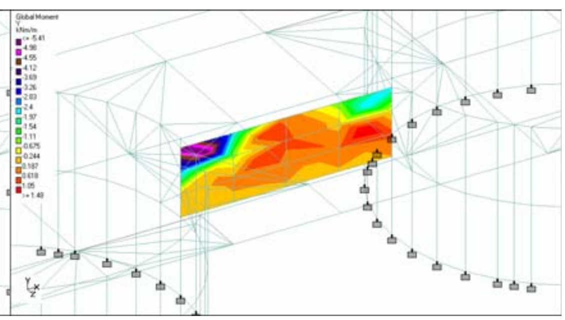
Airy (45 degree - 30 wave position)



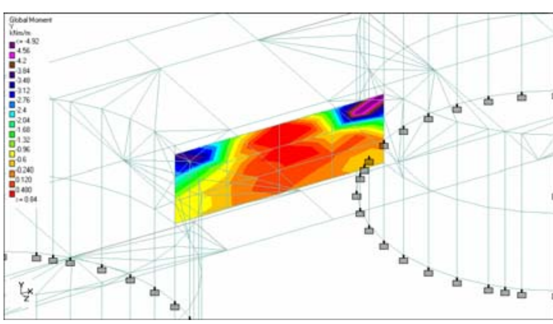
Stream (45 degree - 30 wave position)



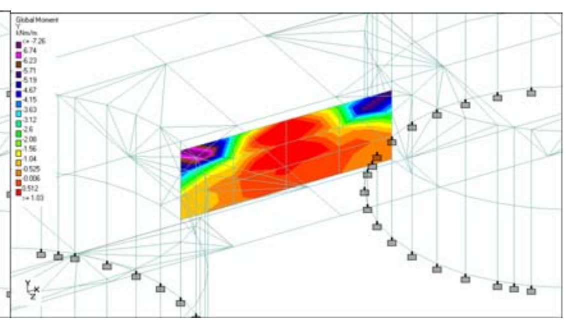
Airy (45 degree - 60 wave position)



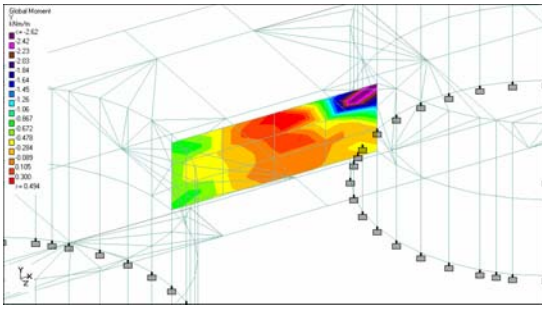
Stream (45 degree - 60 wave position)



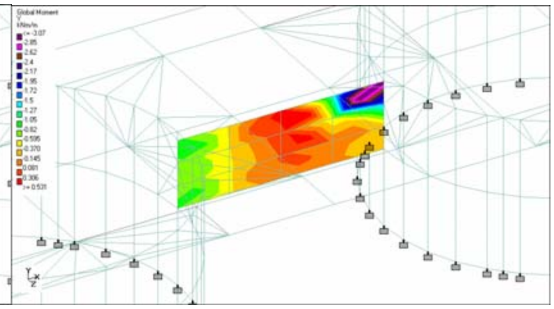
Airy (45 degree - 90 wave position)



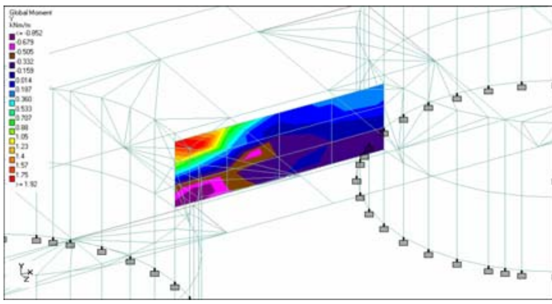
Stream (45 degree - 90 wave position)



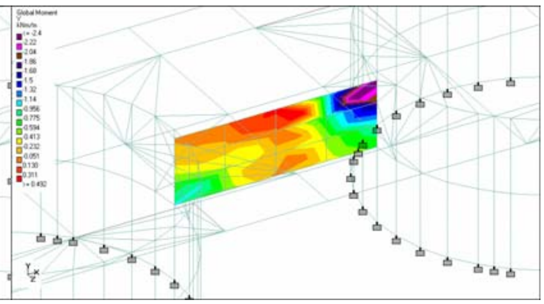
Airy (45 degree - 120 wave position)



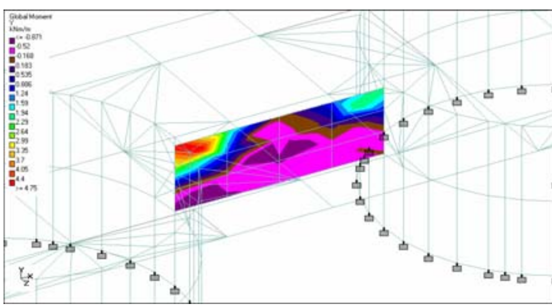
Stream (45 degree - 120 wave position)



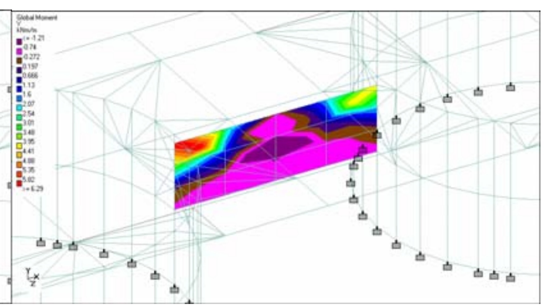
Airy (45 degree - 150 wave position)



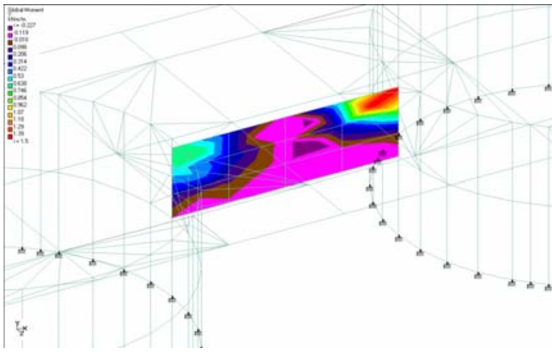
Stream (45 degree -150 wave position)



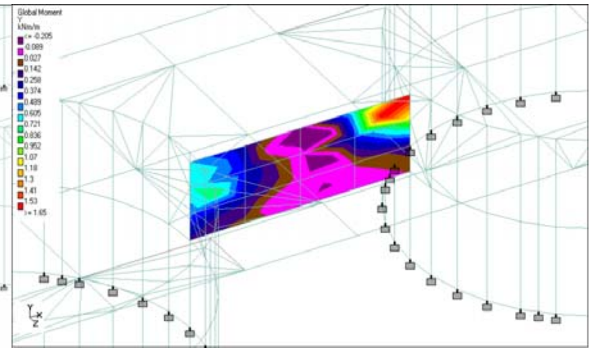
Airy (45 degree - 180 wave position)



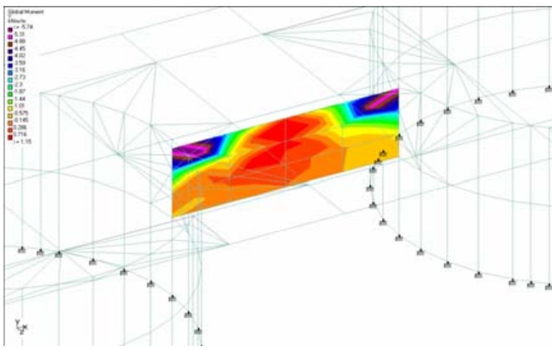
Stream (45 degree - 180 wave position)



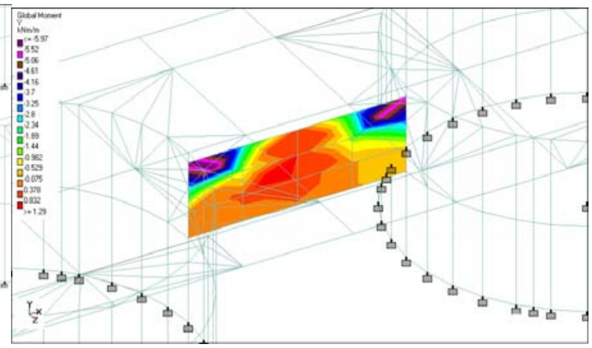
Airy (90 degree - 0 wave position)



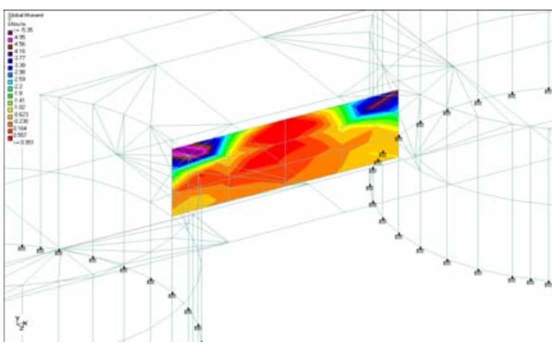
Stream (90 degree - 0 wave position)



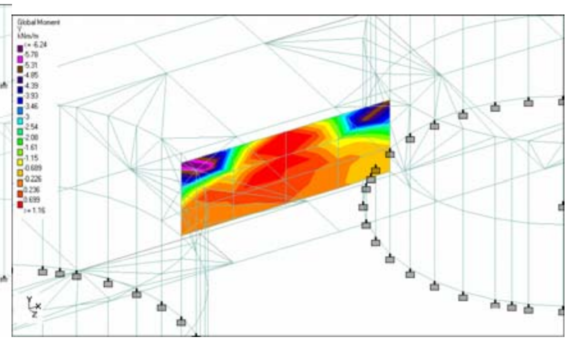
Airy (90 degree - 30 wave position)



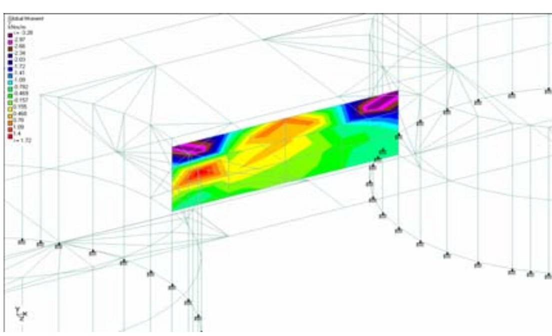
Stream (90 degree - 30 wave position)



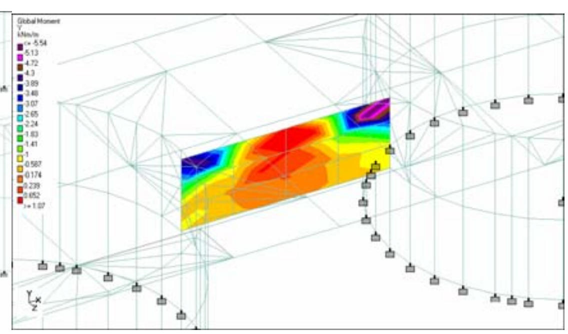
Airy (90 degree - 60 wave position)



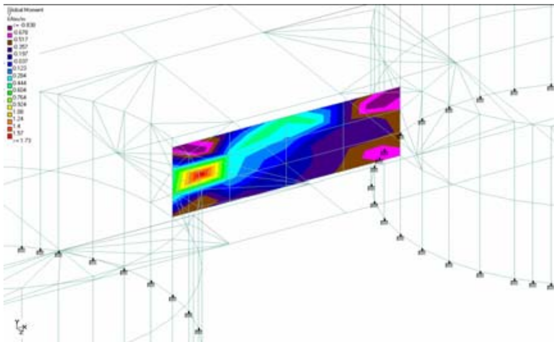
Stream (90 degree - 60 wave position)



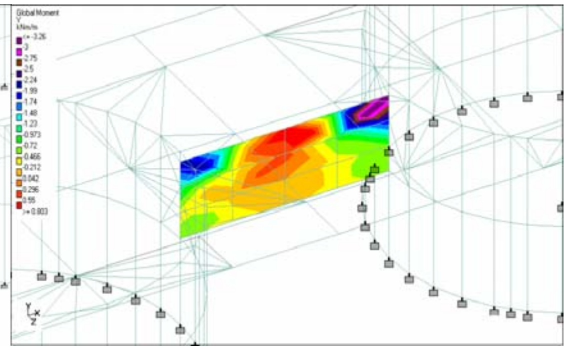
Airy (90 degree - 90 wave position)



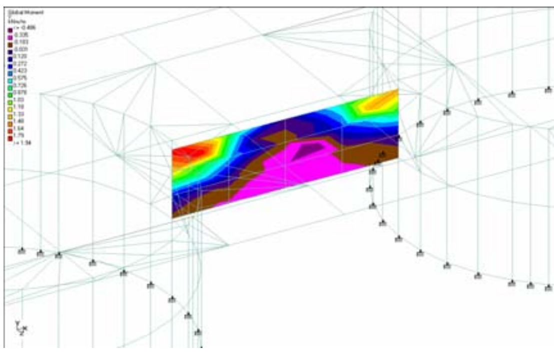
Stream (90 degree - 90 wave position)



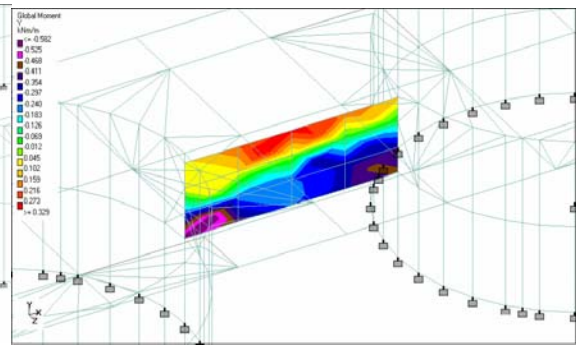
Airy (90 degree - 120 wave position)



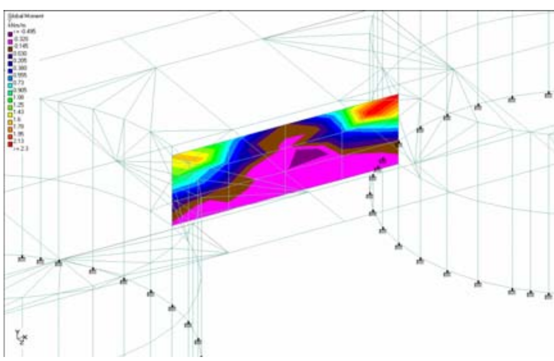
Stream (90 degree - 120 wave position)



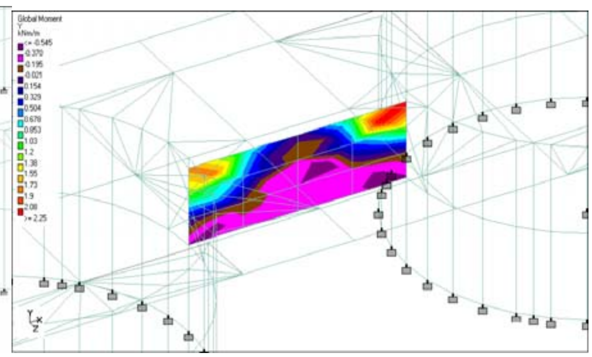
Airy (90 degree - 150 wave position)



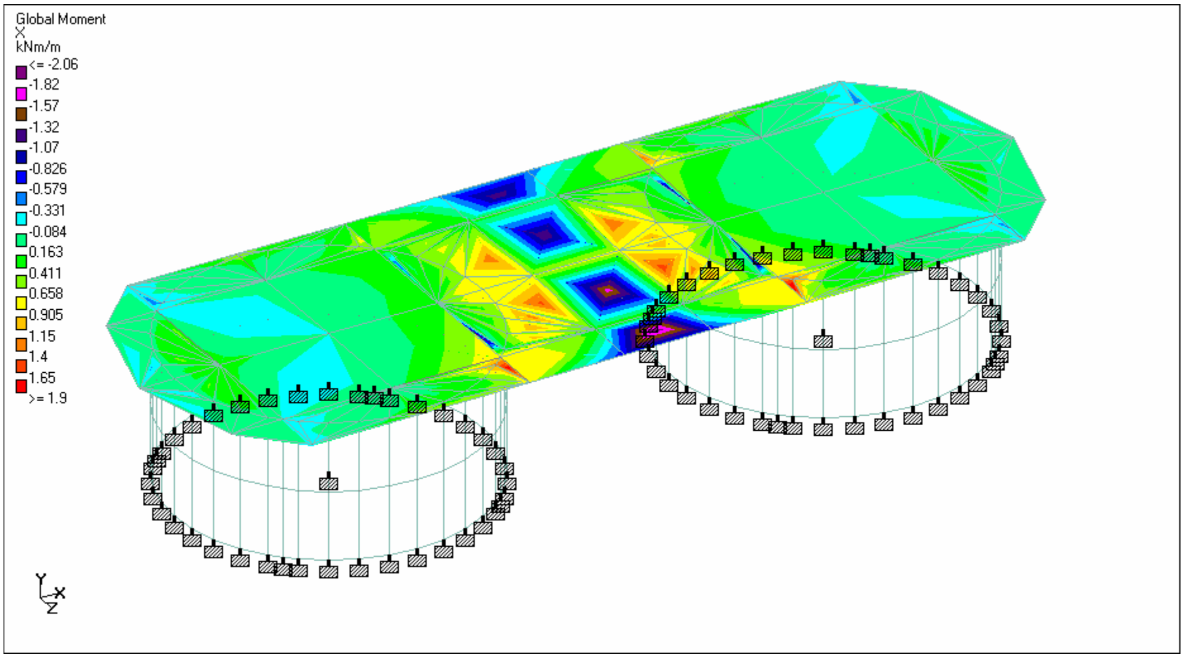
Stream (90 degree - 150 wave position)



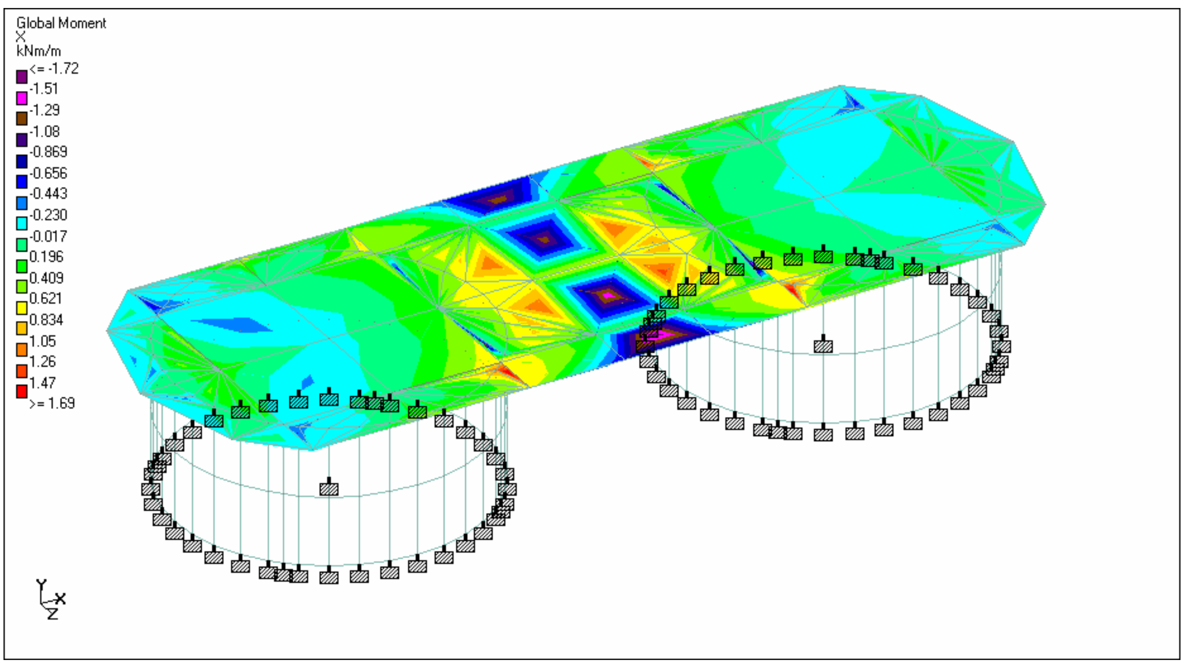
Airy (90 degree - 180 wave position)



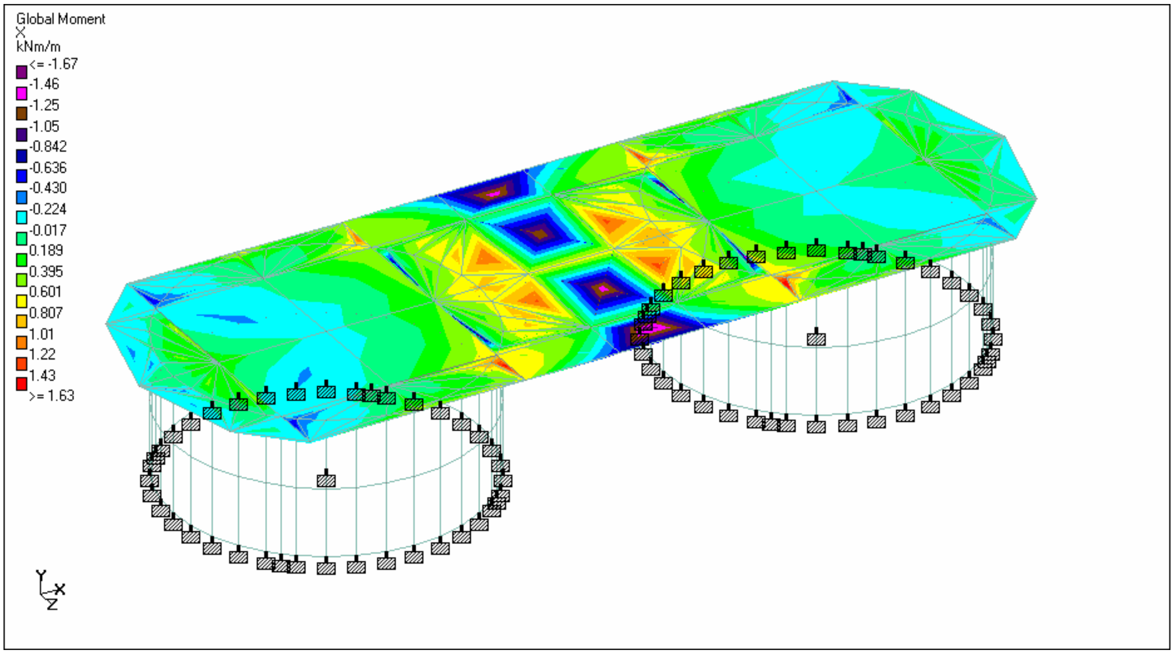
Stream (90 degree - 180 wave position)



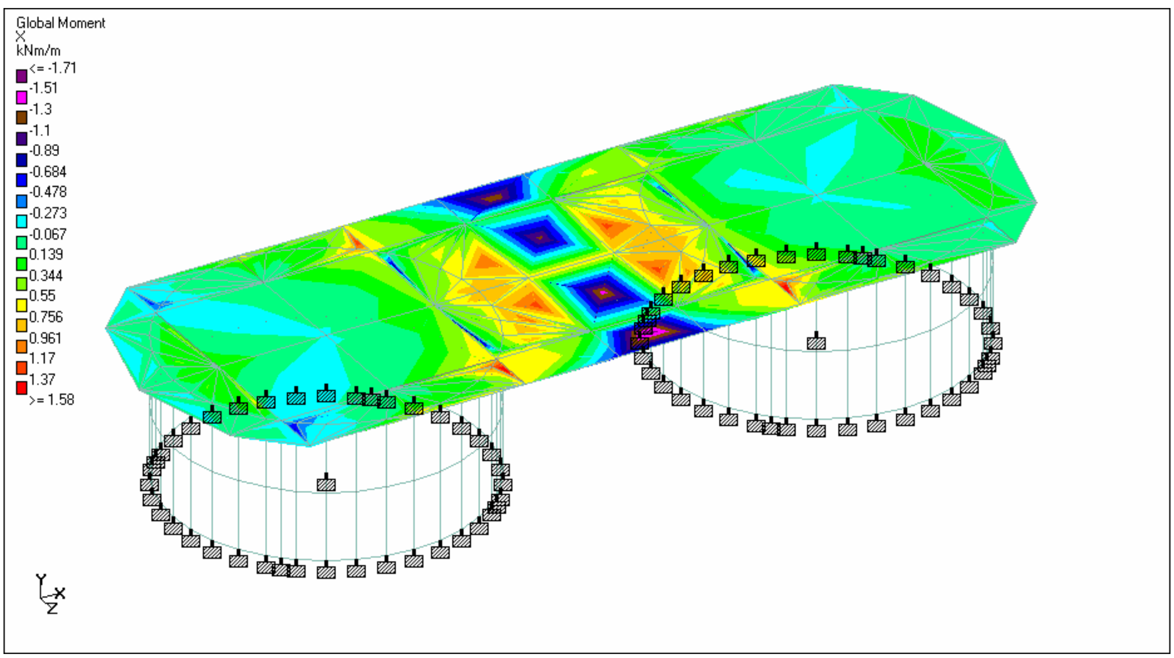
Airy (45 degree – 0 wave position)



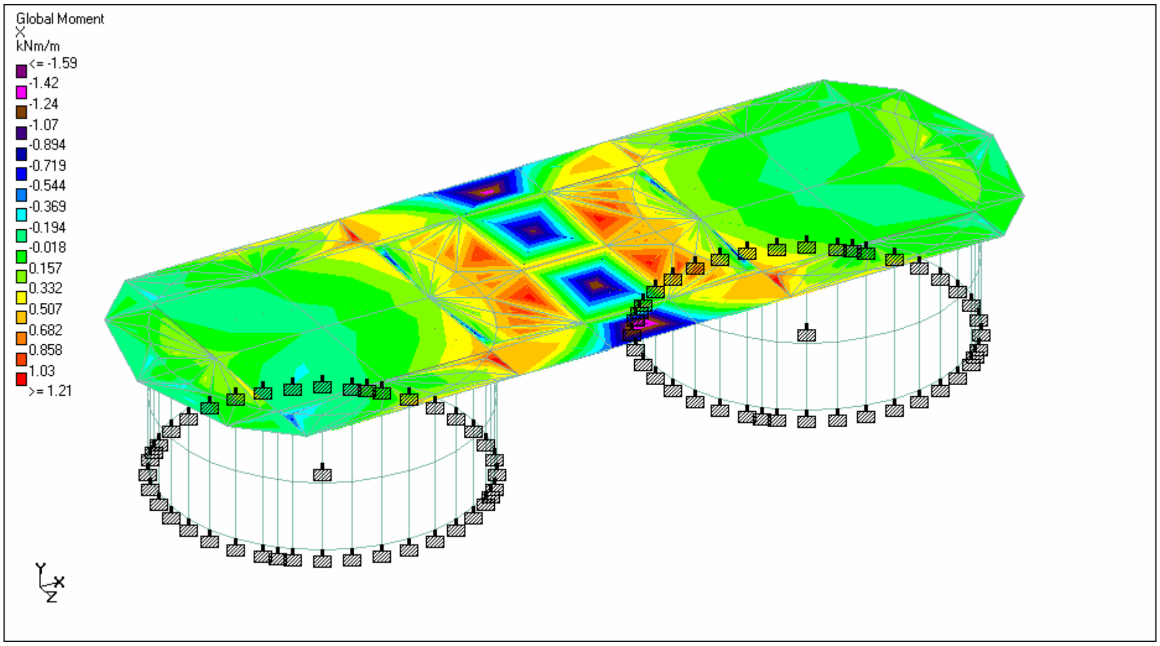
Airy (45 degree – 30 wave position)



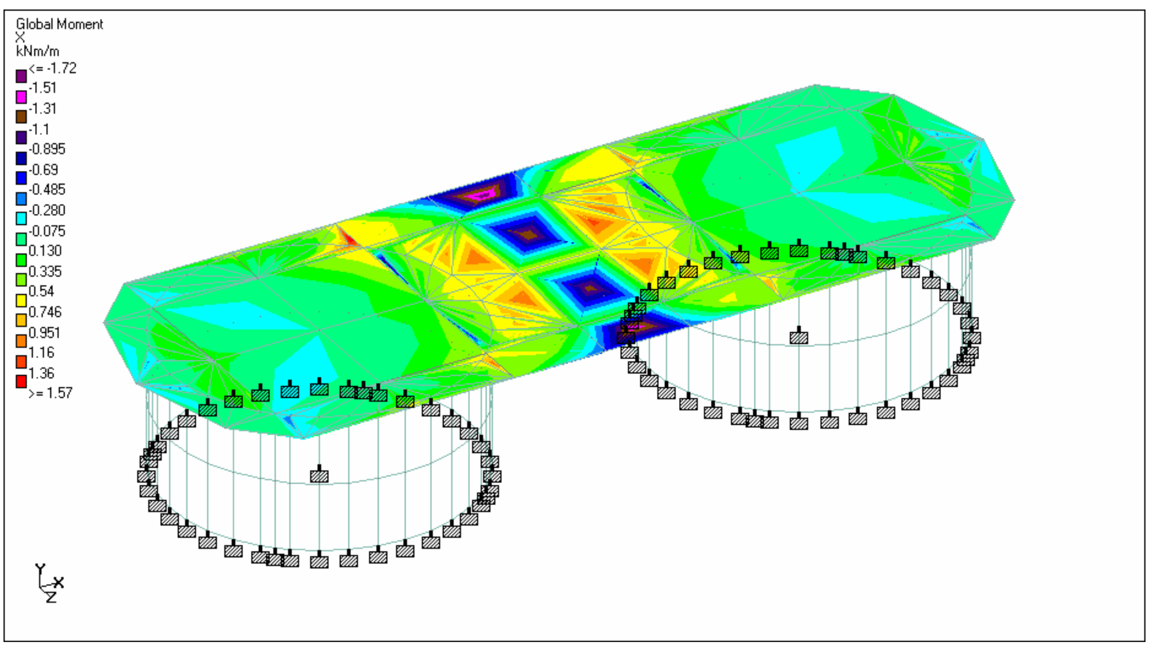
Airy (45 degree – 60 wave position)



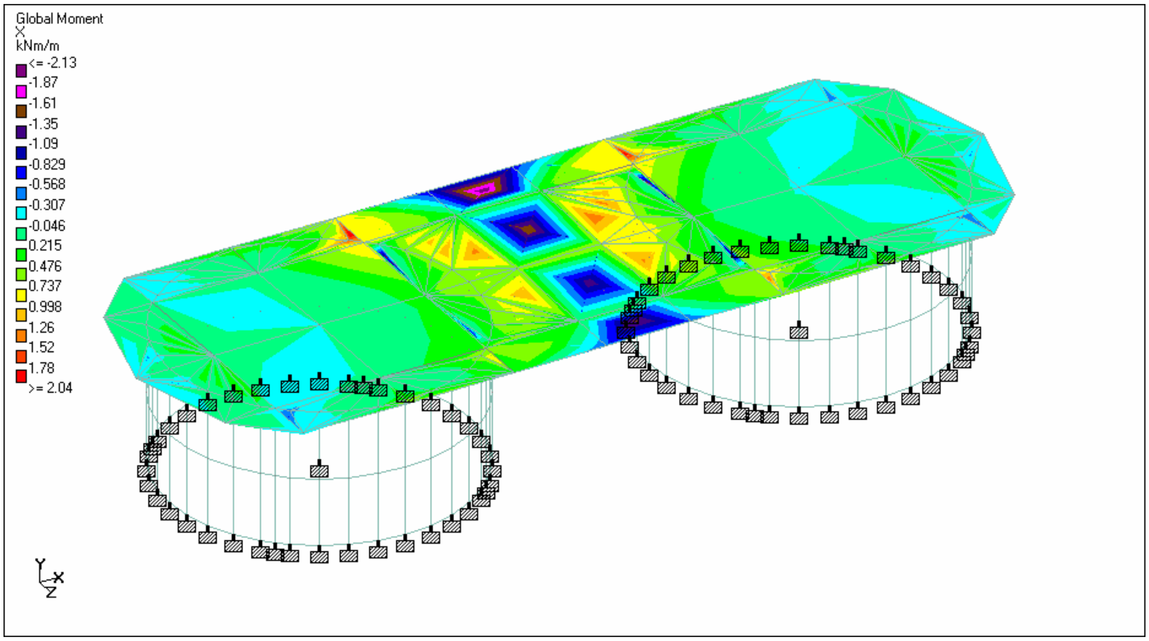
Airy (45 degree – 90 wave position)



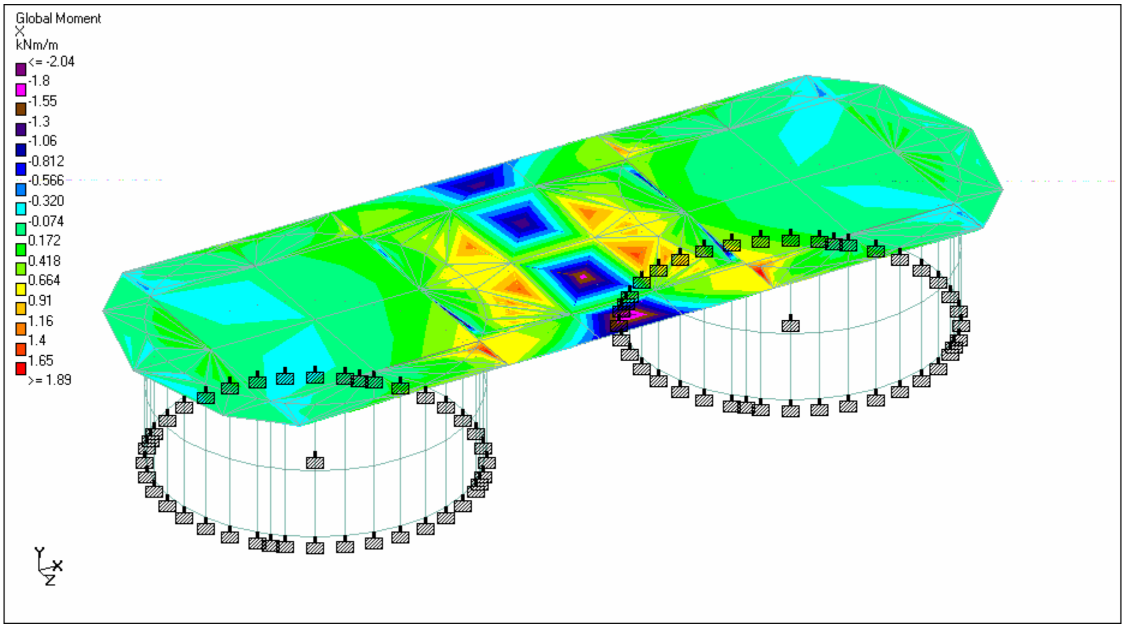
Airy (45 degree – 120 wave position)



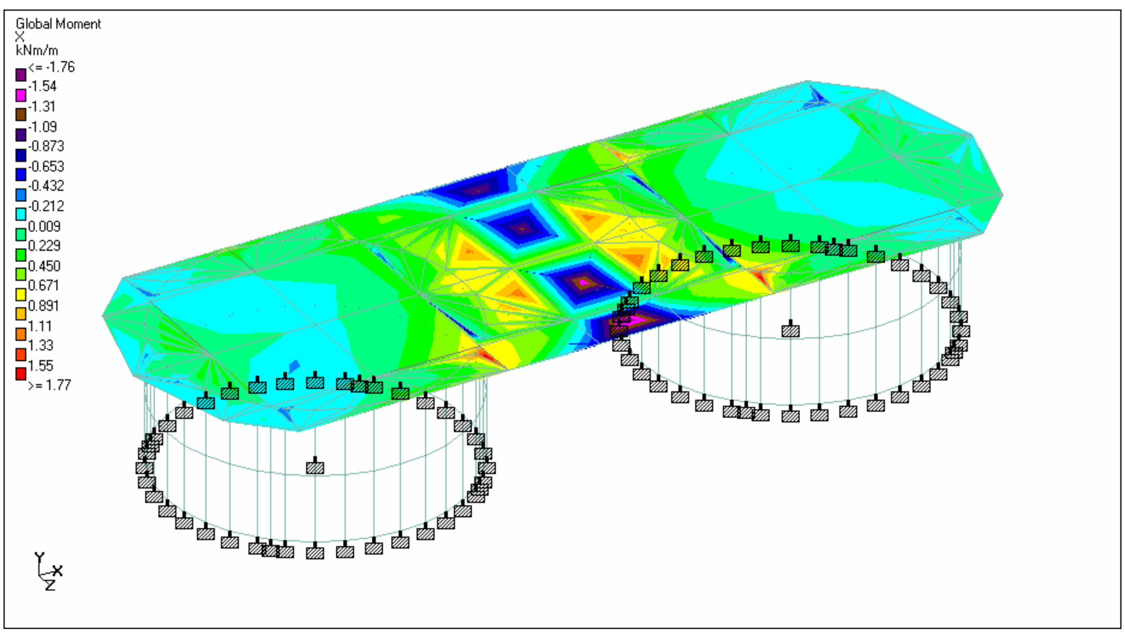
Airy (45 degree – 150 wave position)



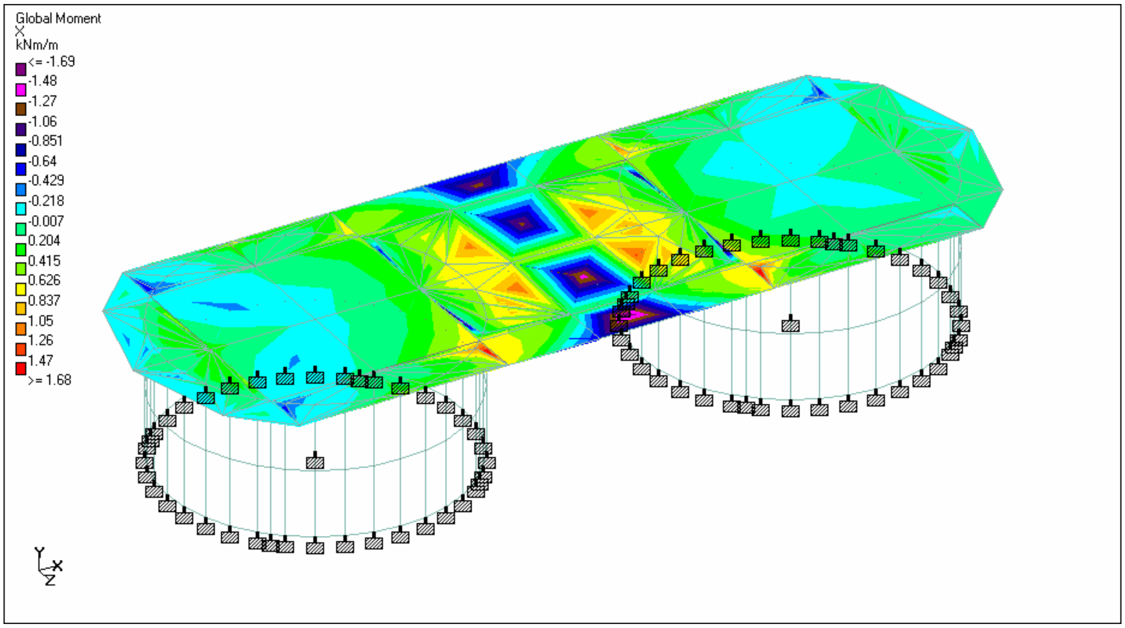
Airy (45 degree – 180 wave position)



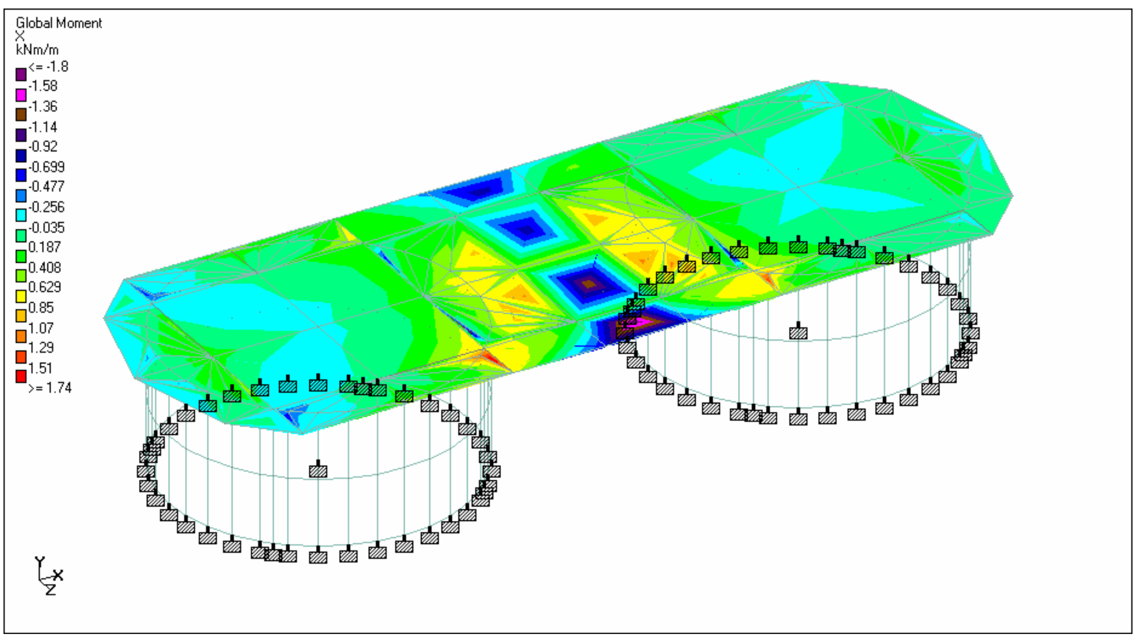
Stream (45 degree – 0 wave position)



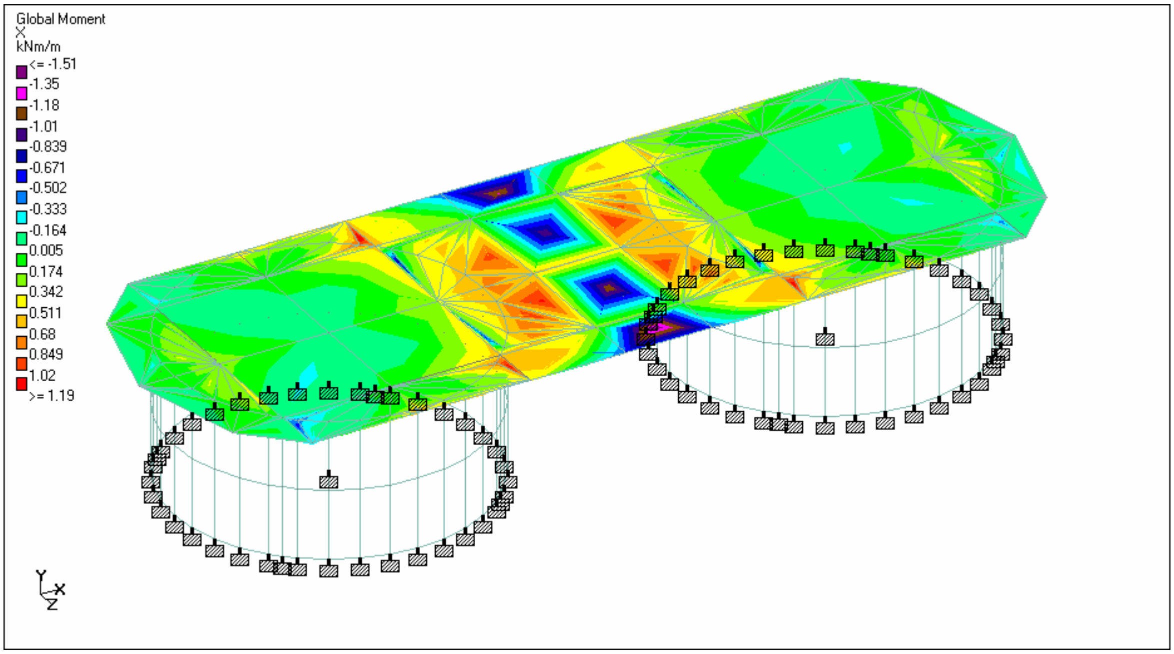
Stream (45 degree – 30 wave position)



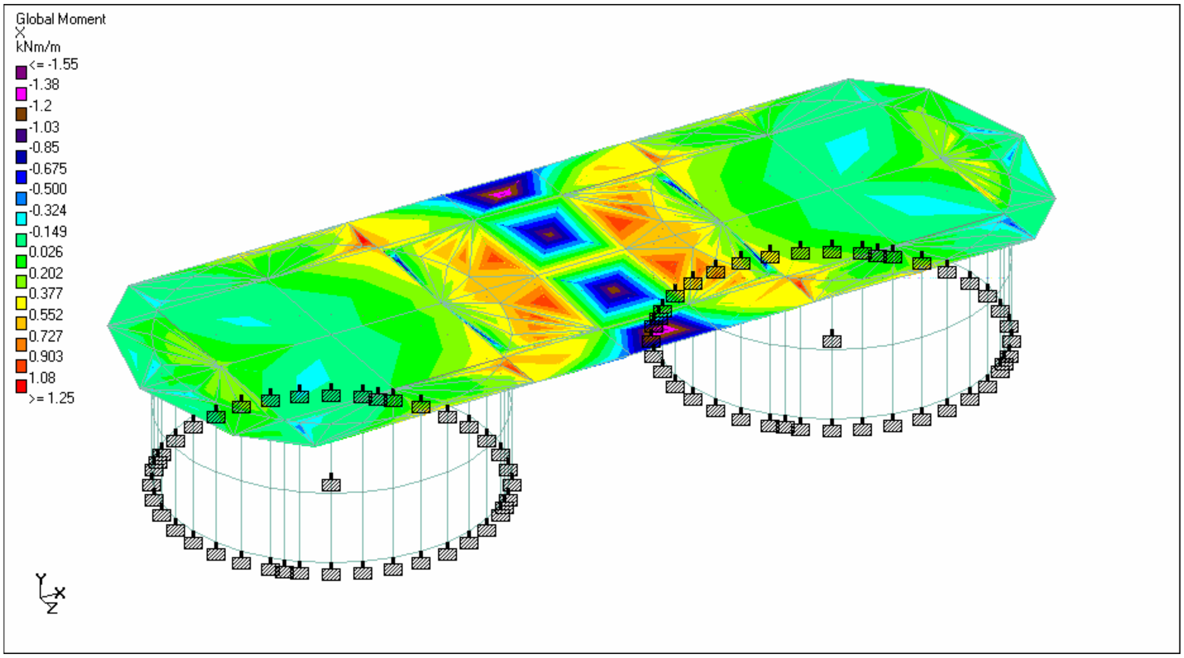
Stream (45 degree – 60 wave position)



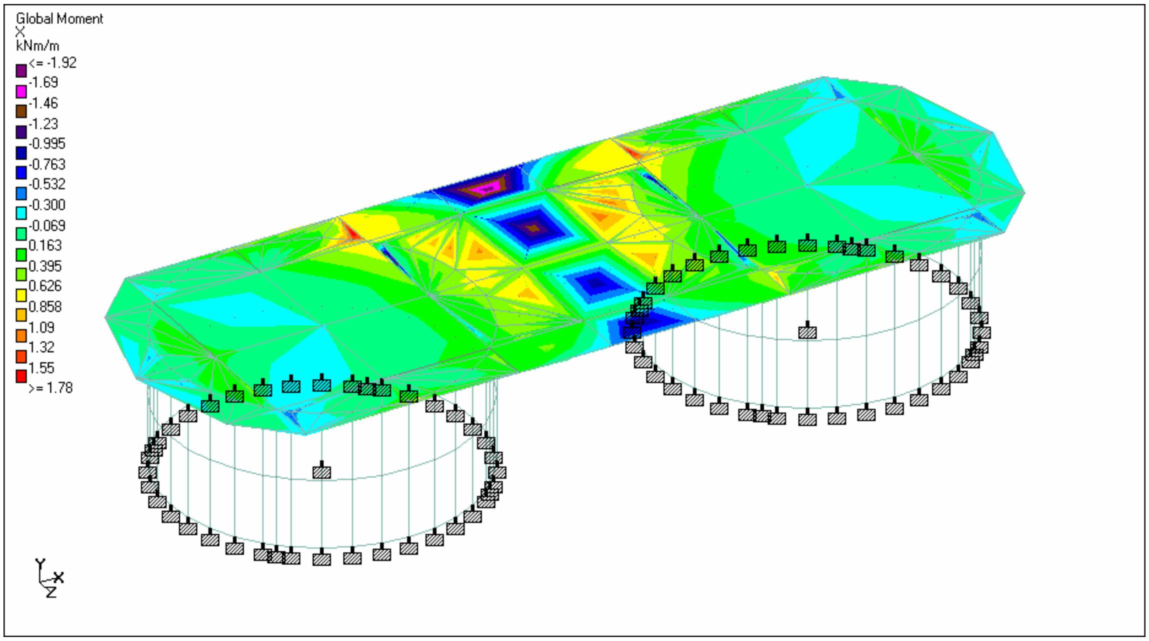
Stream (45 degree – 90 wave position)



Stream (45 degree – 120 wave position)



Stream (45 degree – 150 wave position)



Stream (45 degree – 180 wave position)

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