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FENDER SYSTEMS AND THEIR AFFECT ON BERTHING STRUCTURES WITH SPECIAL MENTION TO IS:4651, BS:6349 AND PIANC GUIDELINES

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Abstract—Water transport is the cheapest and the oldest mode of transport. It operates on a natural track and hence does not require huge capital investment in the construction and maintenance of its track except in case of canals. During the last decades ships have grown larger and larger and the draft of the ship has also increased. Up to now, reliable, theoretically founded design criteria are hardly available. The lack of good design criteria is the prime reason for making researches into the possibilities of an experimental and theoretical determination of berthing forces. A jetty, two design vessels and four different types of fender systems are taken into consideration. The Berthing Energy is evaluated using IS:4651, BS:6349 and PIANC "Guidelines for Design of Fender Systems, 2002" for the largest and smallest vessel. The minimum Berthing Energy from the design vessels is obtained by using the three codes. Using the minimum Energy, the reactions developed for various fender systems is obtained. Based on those values, the fender system best suited for the jetty is found. Using those values, the Jetty is analysed and the Bending Moments developed in the structure for four fenders are considered. For modelling of jetty, STAAD.Pro is used.

Keywords: Berthing Energy, Reactions, Fender System, Bending Moments, STAAD.Pro.

I. INTRODUCTION

Water transport has the largest carrying capacity and is most suitable for carrying bulky goods over long distances. It has played a very significant role in bringing different parts of the world closer and is indispensable to foreign trade. Ports, terminals and harbours play a key role in the shipment of goods around the globe. There are two types of water transport viz. Inland water transport and Ocean-transport.

In the late fifties, conditions suddenly changed. Not only did the draft of ships double in less than twenty years, but the mass increased ten times more from a maximum of 50,000 tons to 5,00,000 tons. Now the new ships required deeper water so that they could be berthed. Not all the ports all over the world facilitate berthing of larger ships. In such cases the larger ship halt at a distance of certain nautical miles from the shore in the sea or ocean and the cargo or the goods are unloaded into smaller ships also known as barges which carry the cargo to the coast. This operation may be economical depending upon many factors like the material which is transported, cost of navigation using barges, etc. Now these small ships are berthed at the port and goods are unloaded from the barges. For ports with deep waters the larger ships are directly berthed at the ports. Berths should accommodate the largest design ships, but they must also cater for small and intermediate ships.

Generally a berthing facility consists of one or more elastic elements (fenders) attached to a rigid structure (finger pier, caisson-type jetty, quay-wall, etc.). The fenders absorb the berthing forces and form a protection for ship and berthing structure. As the maximum permissible berthing force against the side of e.g. a mammoth tanker is distinctly lower than what is acceptable for the berthing structure, the ship is therefore the prevailing factor for fender design. They are first and foremost a safety barrier to protect people, ships and structures. Most fender systems use elastomeric (rubber) units, air or special foams which act as springs to absorb the ship's kinetic energy

The phenomenon occurring during the berthing manoeuvre of a ship are complicated and the fender loads are influenced by a lot of parameters: the configuration of the berthing site, the geometry and the rigidity or hull of the ship, the mechanical properties of the fenders, the speed of approach, the forces exerted by tugs, wind, current and waves, the mode of motion, the keel clearance.

II. CODAL PROVISIONS

A. As per IS: 4651 (Part III) - 1974

When an approaching vessel strikes a berth, a horizontal force acts on the berth. The magnitude of this force depends on the kinetic energy that can be absorbed by the fendering system. The reaction force for which the berth is to be designed can be obtained and deflection-reaction diagrams of the fendering system chosen. The kinetic energy imparted to a fendering system, by a vessel moving with velocity v m/s is given by:

$$\text{Berthing Energy E} = \frac{W_D * V^2}{2g} * C_m * C_e * C_s$$

where

W_D is displacement tonnage (DT) of the vessel in tones
V is the approach velocity of the vessel in m/s, normal to the berth
C_m is the mass co-efficient
C_s is the softness co-efficient
C_e is the eccentricity co-efficient

B. As per BS: 6349 (Part IV) - 1994

$$\text{Berthing Energy, E} = 0.5 * C_M * M_D * C_E * C_S * C_C * V_B{}^2$$

where

C_M is the hydrodynamic mass coefficient
M_D is the displacement of the ship (in t)
V_B is the velocity of the vessel normal to the berth (in m/s)
C_E is the eccentricity coefficient
C_S is the softness coefficient
C_C is the berth configuration coefficient

C. PIANC" Guidelines for Design of Fender Systems, 2002"

For the energy calculation the displacement of a vessel is required. The displacement tonnage (<u>M</u>) of a vessel is the total mass of the vessel and can be calculated from the volume of water displaced multiplied by the water density. In most case the vessel's fully loaded displacement is used in the fender design.
The kinetic energy of the moving vessel may be calculated as :

$$E = 0.5*M*V^2$$

where

E is the kinetic energy of the vessel itself (kNm)
M is the mass of vessel (water displacement) in tonnes
V is the speed of the approaching vessel perpendicular to the berth in m/s
The design energy that has to be absorbed by the fender can be calculated as:

$$E_d = 0.5*\underline{M}*V^2*C_e*C_m*C_s*C_c$$

where

E_d is the design energy (under normal conditions) to be absorbed by Fender System (in kNm)
<u>M</u> is the mass of the design vessel (displacement in tonnes) at chosen confidence level. Usually 95% confidence level
V is the approach velocity of the vessel perpendicular to the berth in m/s
C_e is the eccentricity factor
C_m is the virtual mass factor
C_s is the softness factor
C_c is the berth configuration factor or cushion factor

III. NUMERICAL STUDY AND MODELLING OF JETTY

A. Design Vessels

The design vessel sizes range and characteristics to be considered for design of jetty are as follows :

TABLE I
DETAILS OF THE DESIGN VESSELS

Vessel Type	DWT	L_{OA}(m)	Beam(m)	Loaded Draft(m)
Maximum Ship Size	2000	80	11	3.50
Minimum Ship Size	200	18	5	1.00

Calculation of Berthing Energy

Vessel Characteristics

Type of the Vessel : Other
Dead Weight Tonnage (DWT) : 2000 ton
Displacement Tonnage (W_D) : 2520 ton
Length (L_{BP}) : 80 m
Length (L_{OA}) : 80 m
Draught of the vessel (D) : 3.5 m
Beam width (B) : 11 m

Constants

Acceleration due to gravity (g) : 9.81 m/s^2
Unit weight of sea water (w) : 1.03 t/m^3

Berthing Conditions

Type of Berthing : Quarter point berthing
Berthing Condition : Moderate wind and swell
Berthing Velocity or approach velocity (V) : 0.25 m/s
Vessel approach angle : 10^0

Berthing Structure

Berthing structure comprises of 36 m long × 18 m wide jetty supported on bored cast In-situ piles with superstructure comprising of longitudinal and transverse beams supporting the Deck slab. Finished deck level shall be maintained at RL +16.0 m. Piles are provided at spacing of 6 m c/c in longitudinal direction. Along Transverse direction, 4 piles are provided at spacing of 6 m c/c. The ground level is at RL +4.0 m. The beams are of size 1 m x 1 m and the piles are circular piles of diameter 1 m. The jetty is modelled in STAAD.Pro software.

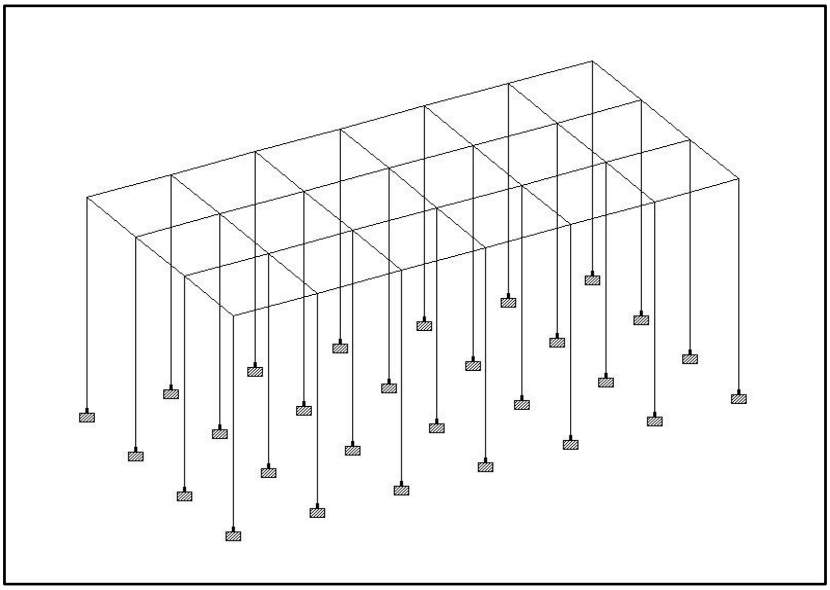

Fig. 1 Isometric view of the Jetty

The structure is loaded in the transverse direction as a nodal load at the deck level at the last node. The value of the load is the reaction developed by the specified fender. The same node is loaded in the longitudinal direction 25% of the load in the other direction. Then the analysis is carried out.

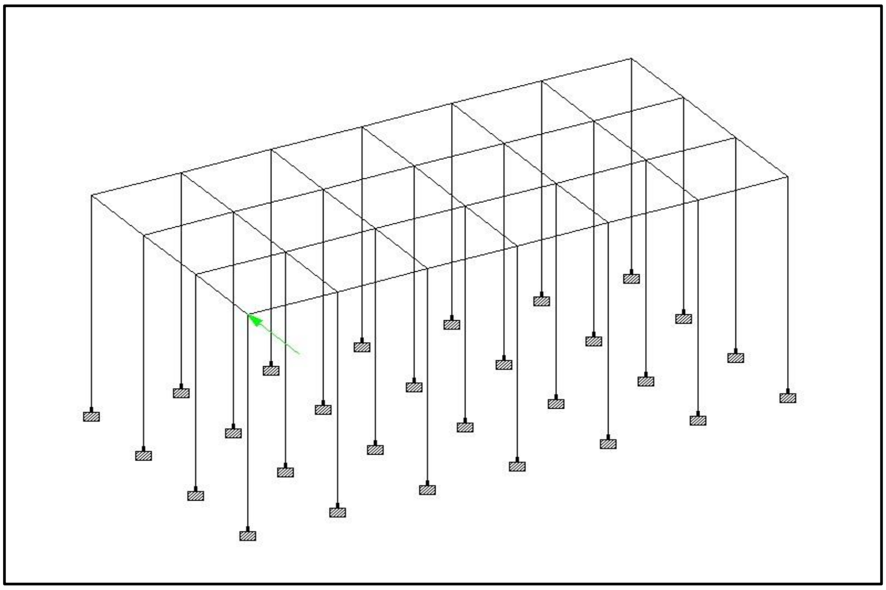

Fig. 2 Load case 1

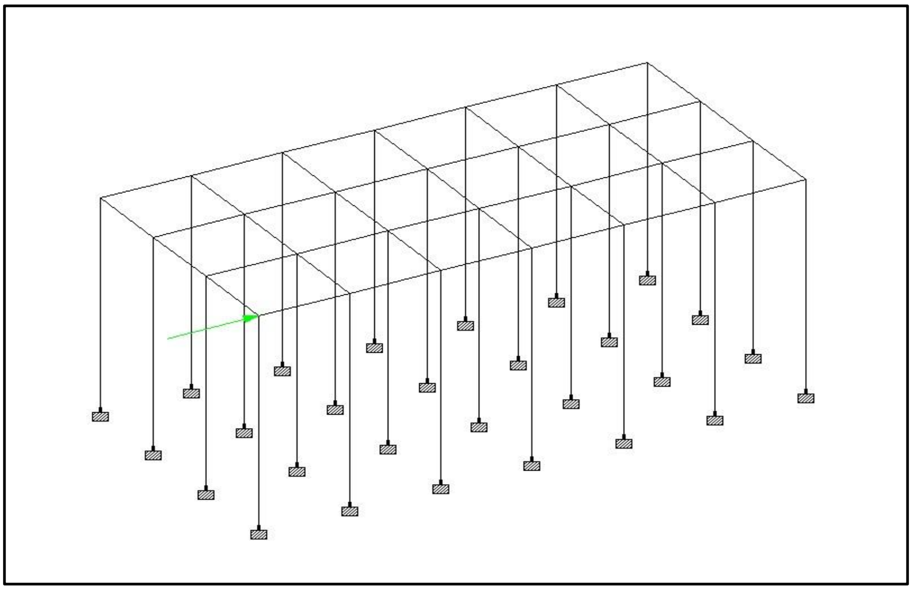

Fig. 3 Load case 2

IV. RESULTS

*A. **Calculation of Berthing Energy as per IS : 4651***

As per IS : 4651 (Part III) – 1974

Calculations for Coefficients

- **Mass Coefficient (Cm)**

if DWT<=20000, Cm = 1+ $\frac{2D}{B}$

where D is the Draught of the Vessel in m and B is the Beam Width in m.

if DWT>20000, Cm = $1+\frac{\left(\frac{\pi}{4}\right)*L*w*D^2}{W_D}$

Since DWT = 2000 DWT

Cm = 1.6363

- **Eccentricity Coefficient (Ce)**

Ce = $\frac{1+(l/r)^2\sin^2\theta}{1+(l/r)^2}$

l = dist from CG of the vessel to the point of contact projected along the waterline of the berth = 18.74 m
r = radius of gyration of the rotational radius on the plane of the vessel = 20.74 m

Ce = 0.5641

- **Softness Coefficient (Cs) = 0.9**

Berthing Energy, E = $\frac{W_D * V^2}{2g} * C_m * C_e * C_s$

E = 6.668 ton m

Factor of safety = 2

Manufacturer Tolerance = 10%

Berthing energy = 143.933 kNm

Considering 2.5 m as vessel contact length,

Berthing Energy to be absorbed = 57.6 kNm/m

B. Calculation of Berthing Energy as per BS : 6349

As per BS : 6349 (Part IV) – 1994

Calculations for Coefficients

- **Hydrodynamic Mass Coefficient (C_M)**

$C_M = 1+\frac{2D}{B}$

where D is the Draught of the Vessel in m and B is the Beam Width in m.

C_M = 1.6363

- **Eccentricity Coefficient (C_E)**

$C_E = \frac{K^2+R^2\cos^2\gamma}{K^2+R^2}$

Where K is the radius of gyration of the ship and may be calculated from the formula:

K = (0.19C_b + 0.11) L

where L is the length of the hull between perpendiculars in m = 80 m

C_b is the block coefficient

$C_b = \frac{\text{displacement}}{(\text{length of hull between perp endiculars} \times \text{beam} \times \text{draught} \times \text{density of water})} = \frac{2520}{80*11*3.5*1.03}$ = 0.7943

K = (0.19*0.7943 + 0.11) * 80 = 20.874

R is the distance of the point of contact from the centre of mass in m = $\sqrt{y^2 + (\frac{B}{2})^2} = \sqrt{20^2 + (\frac{11}{2})^2}$ = 20.742 m

γ is the angle between the line joining the point of contact to the centre of mass and the velocity vector = 25.376°

C_E = 0.9087

- **Softness Coefficient (Cs) = 0.9**
- **Berth Configuration Coefficient (C_C) = 1.0**

Berthing Energy, E = 0.5 $* C_M * M_D * C_E * C_S * C_C * {V_B}^2$

E = 105.394 kNm

Factor of safety = 2

Manufacturer Tolerance = 10%

Berthing energy = 231.867 kNm

Considering 2.5 m as vessel contact length,

Berthing Energy to be absorbed = 92.747 kNm/m

C. Calculation of Berthing Energy as PIANC "Guidelines for the design of fender systems, 2002"

Calculations for Coefficients

- **Hydrodynamic Mass Coefficient (C_M)**

  $C_M = 1 + \frac{2D}{B}$

  where D is the Draught of the Vessel in m and B is the Beam Width in m.

  C_M = 1.6363

- **Eccentricity Coefficient (C_E)**

  $C_e = \frac{K^2 + R^2 * COS^2\phi}{K^2 + R^2}$

  Where K is the radius of gyration of the ship and may be calculated from the formula:

  K = (0.19C_b + 0.11) L

  where L is the length of the hull between perpendiculars in m = 80 m

  C_b is the block coefficient

  $C_b = \frac{M}{L*B*D*\rho} = \frac{2520}{80*11*3.5*1.025}$ = 0.798

  K = (0.19*0.7943 + 0.11) * 80 = 20.933

  R is the distance of the point of contact from the centre of mass in m = $\sqrt{y^2 + (\frac{B}{2})^2} = \sqrt{20^2 + (\frac{11}{2})^2}$ = 20.742 m

  ϕ is the angle between the line joining the point of contact to the centre of mass and the velocity vector = 25.376°

  C_E = 0.909

- **Softness Coefficient (Cs) = 1.0**

- **Berth Configuration Coefficient (C_C) = 1.0**

Berthing Energy, E = $0.5*\underline{M}*V^2*C_e*C_m*C_s*C_c$

E = 117.138 kNm

Factor of safety = 2

Manufacturer Tolerance = 10%

Berthing energy = 257.704 kNm

Considering 2.5 m as vessel contact length,

Berthing Energy to be absorbed = 103.082 kNm/m

TABLE II
BERTHING ENERGY FOR THE VESSEL USING IS CODE, BS CODE AND PIANC "GUIDELINES FOR THE DESIGN OF FENDER SYSTEMS, 2002"

	IS: 4651	**BS: 6349**	**PIANC**
Berthing Energy(kNm)	65.424	105.394	117.138
Reaction on Fender(kNm/m)	57.6	92.747	103.082
Abnormal Berthing Energy(kNm)	143.933	231.867	257.704

For the Berthing Energy obtained by IS Code, the Reaction has been calculated using Trellborg Marine Systems Catalogue.

TABLE III
BERTHING ENERGY AND REACTION FOR DIFFERENT TYPE OF FENDERS

Fender Type	**Cell Fender**	**Super Arch Fender**	**Super Cone Fender**	**Unit Element**
Berthing Energy (kNm)	144	154	148	146
Reaction force (kN)	409	457	352	316

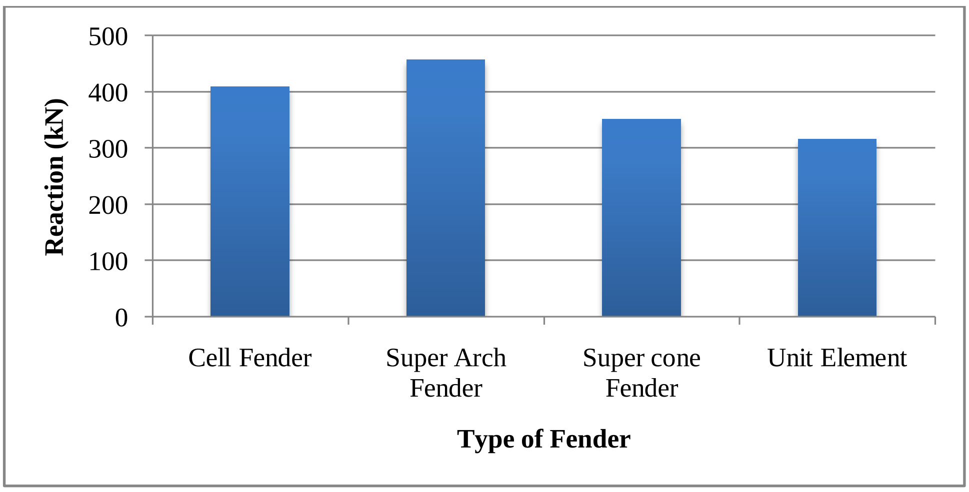

Fig. 4 Variation in Reaction forces for different Fenders

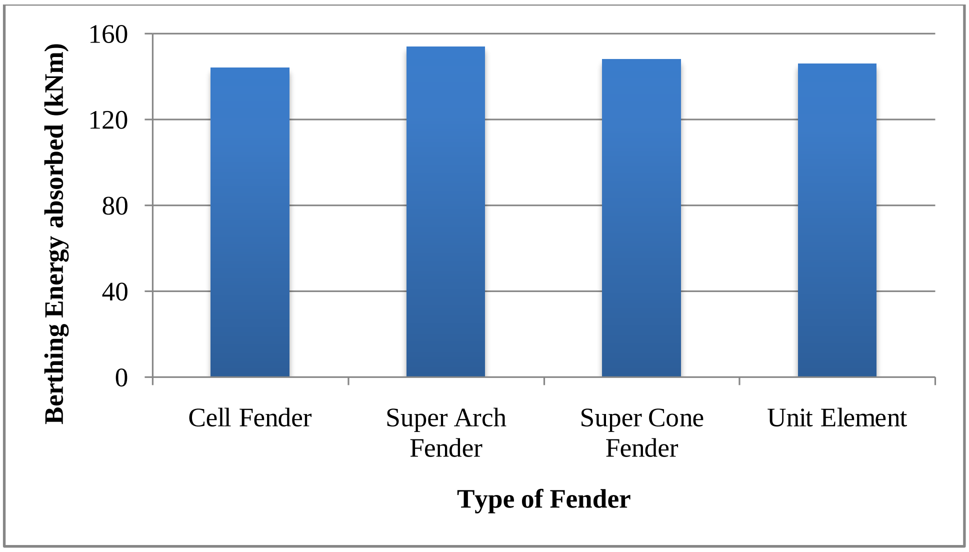

Fig. 5 Variation in Berthing Energy for different Fenders

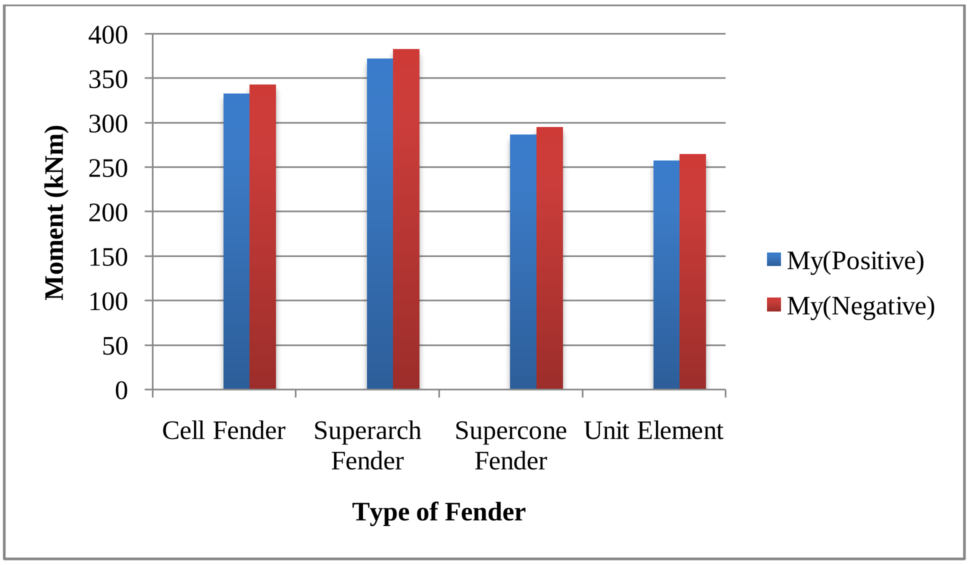

Fig. 6 Variation in Moments developed for different Fenders

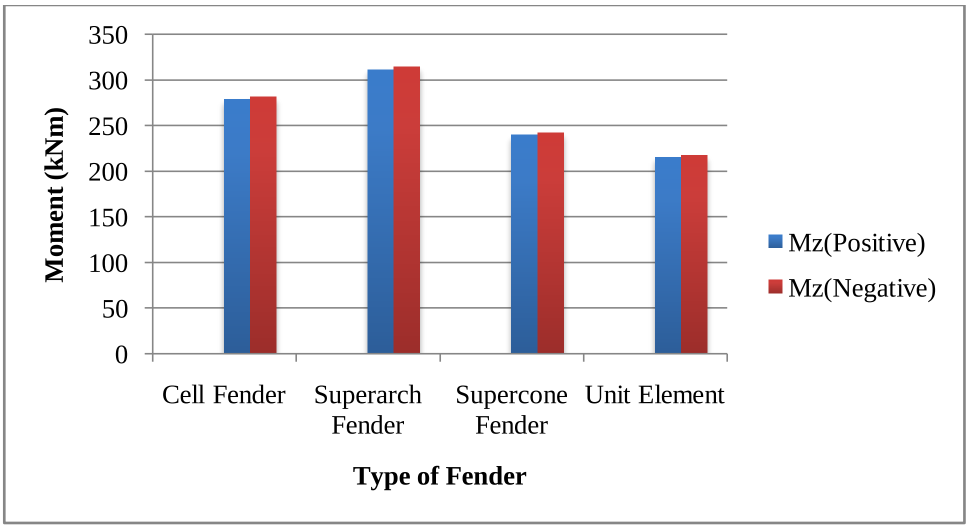

Fig. 7 Variation in Moments developed for different Fenders

V. CONCLUSION

Following conclusions were taken from results obtained as above:

- The Berthing Energy obtained by BS Code and PIANC Guidelines give more conservative values as compared to IS Code.
- The value as per BS Code gives 61.1% greater value than IS Code and PIANC gives value of 79% greater than as per IS Code. However, the difference in values obtained by BS Code and PIANC is less as compared to IS Code.
- The Berthing Energy obtained by using PIANC Guidelines is 11.14% more than value obtained using BS Code.
- The reaction developed is minimum for Unit element Fender, thus the moments developed in piles will be minimum for this Fender and the reinforcement will also be minimum.
- The Bending Moment developed in the structure is minimum for the Unit Element Fender, thus it can be concluded that for the Jetty installed with Unit element Fender can be designed economically.

REFERENCES

LIST OF CODES

1. IS: 4651 Part 3-1974," Code of practice for planning and design of ports and harbours", Bureau of Indian Standards (BIS).
2. BS: 6349 Part 4-1994," Code of practice for design of fendering and mooring systems", British Standards Institution.
3. PIANC "Guidelines for the design of Fender System-2002."

LIST OF CATALOGUES

1. Trellborg Marine Systems