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RESEARCH ARTICLE

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Comparative Study on Analysis and Design of LNG Terminal on West Coast of India using Concrete piles and Steel piles

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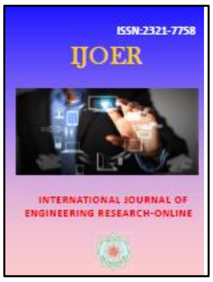

ABSTRACT

As the world struggles to find new sources of energy, it is clear that the fossil fuels will continue to play a dominant role in the foreseeable future .Within the hydrocarbon family the fastest growing hydrocarbon is Natural gas. So, the transportation of Liquefied Natural Gas has been playing an important role in country's economy. In India already some ports have LNG terminals but they have less capacity hence there is a need in development of new LNG terminals with high capacity. As the cost of construction of LNG terminals is more expensive, in the present case study a LNG terminal (of capacity 36, 000 – 50,000m^3 up to 1, 45,000-2, 10, 000 m^3 (Q-flex) in size) on west coast of India is analysed and designed with concrete piles and steel piles using STAAD. Pro 2007 software with different parameters to find out the best and economical structure. The results shows cost of construction is 30– 45 % higher for structures with concrete piles. Pile defection is smaller for all the marine structures with steel piles compared to concrete pile structures. From the comparative study, it can be concluded that, marine structures with steel piles are the economical one

1.INTRODUCTION

The LNG industry would continue to play an important role in the economy in the coming decades. Therefore, creation of facilities to handle enhanced volumes of LNG products at Indian ports holds critical importance. Presently, India is 6th largest LNG importer, importing 13.5 MMTPA. India's first LNG terminal was started by Petro net (PLL), a partnership by GAIL, IOCL, BPCL, GDF Suez, the Asian Development Bank and ONGC. Sooner, Shell and Total commissioned Hazira terminal. Another long awaited projected Dabhol started in Maharashtra port and Kochi terminal of Kerala. Natural gas currently accounts for 12% of total primary energy and expected to rise to 20% by the end of 2025 and the share of LNG imports in natural gas has risen from nil in 2003 to around 40% by end of 2012

LNG Jetty

A pier or jetty is a structure projecting into water, in a harbor basin. Jetties are also located in open water outside actual harbors. A jetty consists of number of structures such as berthing dolphin, mooring dolphin, loading platform, and trestle to shore, each of which has a special type of functions. The mooring dolphins pick up the pull from hawsers. The berthing dolphins support fenders, which absorb berthing impacts. The loading platforms support special loading or unloading equipment but normally no horizontal forces apart from the wind loads on the equipment are acting. Based on the material of construction, the jetty structures are classified as follow:

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1) Timber jetties
2) Iron and steel jetties
3) reinforced concrete jetties

Fig. 1 Reinforced concrete LNG Terminal over View (source: www.marineinsight.com)

STAAD.Pro 2007

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STAAD.Pro allows structural engineers to analyse and design virtually any type of structure through its flexible modelling environment, advanced features and fluent data collaboration.

2.METHODOLOGY

General Arrangement

The LNG jetty consists of one unloading platform, 4 breasting dolphins (B.D1, B.D2, B.D3, and B.D4), 6 mooring dolphins (MD1 to MD6), approach trestle, cat walks.

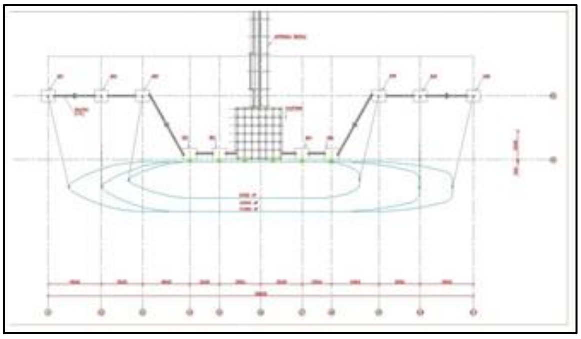


Fig 2.1 Overall lay out of LNG jetty with unloading platform, B.D, M.D

For the purpose of this document, the marine civil and structural works are described as follows with arrangement of structures and cross section.

Unloading Platform

- It contains a main deck
- Major equipment on main deck of the unloading platform includes the LNG unloading arms (3 each), vapour return arm (1each), fire protection systems, hazard monitoring/safety systems, nitrogen receiver, and Knock-Out (KO) drum.

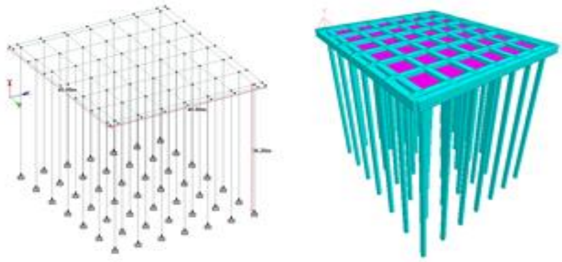


Fig 2.2 Unloading platform STAADPro. Model

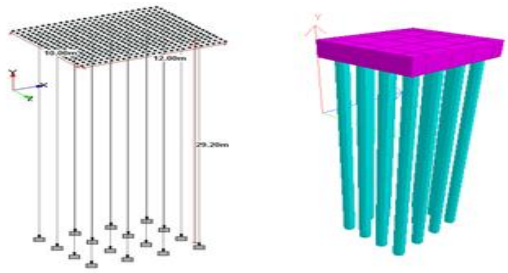
The equipment serves to support the unloading of /LNG from the carrier to the terminal storage tanks.

Structural elements consist of:

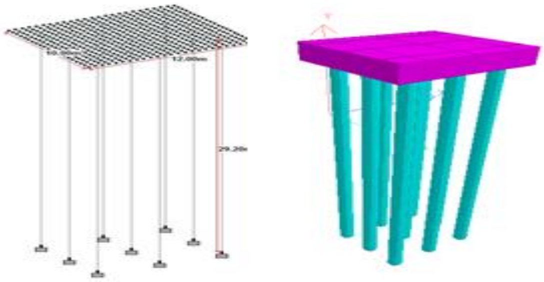
- Vertical / rake RCC piles
- Precast pile muff
- Precast + cast in situ / cast in situ RC cross beam and longitudinal beams
- Precast + cast in situ / cast in situ RC deck
- Structural arrangement to support catwalk

Mooring and breasting dolphins

There are six mooring dolphins and four breasting dolphins. Mooring dolphins are named as MD1, MD2, MD3, MD4, MD5 and MD6.Breasting dolphins are named as BD1, BD2, BD3 and BD4.



2.3 Breasting Dolphin STAADPro model



2.4 Mooring dolphin STAAPro Model

- All mooring and breasting dolphins shall be equipped with Quick Release Mooring hooks
- Any two of mooring dolphins shall be equipped with Berthing Aid System (BAS display)
- All breasting dolphins shall be equipped with fender system

All dolphins shall have elevated supporting system to receive catwalk

Structural elements consist of:

- Vertical / rake RCC piles
- Cast in situ RC deck
- RC Fender supporting system in BD
- Steel structural system to support catwalk

UNITS

- The international system of units (S.I.) shall be used for the design and detailing of all Items unless specified otherwise.

2.1 DESIGN LIFE

- The design life of above mentioned structures shall be 50 years

2.2 METHOD OF DESIGN

- The loads acting on the structures are calculated in accordance with IS 4651 (PART-3), & IS 875 (wind load)
- All RCC piles shall be designed using Limit State method in accordance with IS 456-2000 & IS 2911 (5 parts)
- All other structural steel members shall be designed using working stress method in Accordance with IS 800.
- Reinforced concrete members shall be designed using limit state design method as per IS 456: 2000.
- Three-dimensional structural analysis of structure shall be conducted under all specified Load combinations using STAAD Pro.
- Structural modelling shall consider pile fixed at fixity depth below global scour level for all piles.
- Local scour shall be considered below global scour additionally for 10% of piles out of all piles of respective structural elements in modelling.

2.3 LEVELS

- All levels are related to chart datum (± 0.00 m)

Sea water levels

Table 2.1 Tide levels

Highest Astronomical Tide (HAT)	+4.10 m
Mean High Water Spring (MHWS)	+3.4m
Mean High Water Neap (MHWN)	+3.0 m
Mean Sea Level (MSL)	+2.0 m
Mean Low Water Neap (MLWN)	+1.30m
Mean Low Water Spring (MLWS)	+0.60m
Lowest Astronomical Tide (LAT)	-0.5 m

Structure levels

Levels for structures to be used in design are as follows:

Unloading platform

Table 2.2 Unloading platform Structure levels

Top of main deck	+14.5 m CD
Existing sea bed level	-14.5 m CD

Mooring dolphin

Table 2.3 Mooring dolphin Structure levels

Top of main deck	+8.5 m CD
Existing sea bed level	-13.5 m CD

Breasting dolphin

Table 2.4 Breasting dolphin Structure levels

Top of main deck	+8.5 m CD
Existing sea bed level	-13.5 m CD

2.4 ENVIRONMENTAL CONDITIONS

Rain

- The region is affected by South Western Monsoon between mid-June and mid-September.
- The long term average rainfall from South-West monsoon is 400mm.

Visibility

Visibility at the port is generally good throughout the year even during monsoon or Cyclones except for a few early morning hours for 3 to 4 days in the month of January & February.

Temperature

- The average minimum winter and average maximum summer temperatures are 10^{o}C and 45^{o}C respectively.
- Design maximum peak temperature is 50^{o}C.

Wind, wave and current

- Wave and current forces on substructures shall be calculated using the Morrison Equation with particle velocities to be calculated by using relevant order of Stokes wave theory.
- Wave shoaling effect shall be considered for calculating wave force for shallower portion of approach.
- Drag coefficient CD shall be considered as per shore protection manual figure 7-85

(Variation of drag coefficient with CD with Reynolds number)

- Inertia coefficient Cm shall be considered as per shore protection manual page 7-444, Equation 7-53.
- Current force at any intermediate point shall be interpolated between force at surface and mud line with triangular distribution.

Normal conditions (With tanker moored)-

Waves

Table 2.5 operational wave's details

Significant wave height (Hs)	2.1m
Time period	7.8 s
Direction of approach	245^{0}N
Storm surge	0.0m

Wind (Tanker moored condition)

Basic wind speed: 22 m/s from any direction

Table 2.6 Current velocity

Near surface	1.0 m/s
Near bottom	0 m/s

For these conditions normal load factors are applicable.

Analysis of the various structures shall be for two water levels, viz

- MLWS, with associated wave and current.
- MHWS, with associated wave and current

Cyclone/Extreme condition (Without tanker moored)

Waves at -16m CD

Table 2.7 Extreme wave's details

Design maximum significant wave height (Hs)	6.5m
Time period	10 s
Direction of approach	245KN
Storm surge	1.8m

Wind

Basic wind speed: 55 m/s from any direction.

Current velocity

Table 2.8 Current at -14.5m CD

Near surface	1.80 m/s
Near bottom	0 m/s

Analysis of the various structures shall be for two water levels, viz

MLWS + Storm surge, with associated wave and current.

MHWS + Storm surge, with associated wave and current.

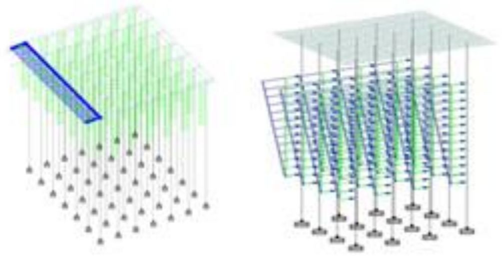


Fig 2.5 Unloading platform & Dolphins with wind, wave & current load in X direction

2.5 MARINE GROWTH

An allowance in dimension of the submerged structures due to marine growth shall be taken in account.

For design 200 mm extra width (Diameter + 2x100 mm) shall be added to the dimension of any submerged element.

This allowance is applicable for all construction elements from +3.4m CD (MHWS) to design mud line (including scour).

Cover to reinforcement

The clear cover to the outermost reinforcement (for precast or cast in situ RC) shall be as follows:

Table 2.9 Marine structures

RC piles, columns	75 mm
Dolphin deck, roadway slabs, Longitudinal and cross beams and pile muff	50 mm

2.6 GEOTECHNICAL

Marine structures

The foundation consists of bored cast in situ concrete piles.

Pile safety factor for axial pile capacity (tension and compression):

Operating conditions: 2.5 in axial compression and 3.0 in axial tension

Extreme conditions: 1.5 in axial compression and 2.0 in axial tension

The lateral load capacity, end bearing and skin friction capacity considering pile group effect shall be checked and the pile spacing shall be decided accordingly.

2.7 MATERIALS

Concrete

Cast in Situ Concrete

M40 Compressive strength (28 days): 40 N/mm²

Precast Concrete:

M40 Compressive strength (28 days): 40 N/mm²

Partial Safety Factor Ym for Material Strength

Concrete Ym = 1.5

Reinforcement Ym = 1.15

Ym values given in IS 456 are already incorporated in the equations and tables for limit state design

Reinforcement

Rebar Fe 415 (IS 1786: 1985) (Corrosion resistant steel)

Minimum yield stress : 415 N/mm²

Tensile strength :485 N/mm²

Elongation : 14.5%

Steel Piles

S355 grade steel section

Diameter - 1.219m

Thickness – 0.022m

Yield strength – 345 N/mm²

Tensile strength – 470 N/mm²

3 LOADS

3.1 Dead loads

The specified dead load for a structural member consists of the weight of the member,

The weight of all materials of construction incorporated in the structure to be supported permanently by that member and the weight of permanent equipment

In assessing dead loads, the following material unit weight shall be used:

Table 3.1 Dead weight of materials

Steel	78.5 kN/m3
Concrete (reinforced)	25.0 kN/m3
Concrete (plain)	24.0 kN/m3
Backfill	20.0 kN/m3 (wet),
	18.0 kN/m3 (dry)
Marine growth	11.0 kN/m3
Seawater	10.30 kN/m3
Wearing coat	24.0 kN/m³

The dead load due to following shall be considered in the design

Marine unloading arms, KO drum, Fire monitor towers, Operators cabin, Open shelter Foam drum, Nitrogen receiver, Hydraulic power unit, Dry chemical powder unit, Jetty control room monitor towers.

Dead load for following shall be considered:

Fenders, quick release mooring hooks and other miscellaneous structural items

3.2 Variable loads

Live Load General

Following minimum live loads shall be considered in the design of the structures.

Unloading Platform

Operating live load and friction load due to piping, catwalk etc.

- 10 kN/m² UDL in area not occupied by piping.
- Deck shall be checked for Class A loading with impact factor as per IRC or 200KN tire mounted crane whichever is more critical.
- While examining the effects of Class A / crane loading, the remaining area shall be assumed to be covered by UDL (piping/live load).
- 5 kN/m² UDL on stair cases.

Breasting and Mooring Dolphins

- 5 kN/m2 UDL.

Wind force

The basic wind speed is as given in basic design data. The design wind speed shall be calculated as per IS: 875 with

K1 = 1.0, K2 = 1.1 and K3 = 1.0 for Berth

Vz =K1*K2*K3*Vb

Pz =(0.6 *Vz*Vz)

3.3 Seismic force

Earthquake forces shall be adopted as applicable for the site as per IS 1893 – 2002

Design horizontal seismic coefficient shall be evaluated as per procedure detailed in IS 1893-2002.

Various parameters are as follows:

Table 3.2 Seismic Load Values

Seismic zone :	V
Design horizontal seismic coefficient, Ah	ZI(Sa/g)/(2R)
Zone Factor Z :	0.36
Importance Factor I:	5
Response Reduction Factor R :	5 (for steel piles)

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Response Reduction Factor R	3 (for concrete piles)
Type of Soil	Hard soil
Damping	5% for Reinforced concrete

Average response acceleration coefficient Sa/g :
Sa/g shall be derived from the fig. 2 on Page 16 of IS 1893.
Time period of specified structures shall be evaluated by STAAD analysis considering Dead load + Super imposed dead load + 50% Live load.
Therefore seismic load Feq =Ah*(dead wt. of structure + 50% live load)
Seismic Forces due to Live Load
The seismic force shall be calculated for 50% of the design live load.
Substructure (RCC Piles)
The following mass has to be taken in account:

- Mass of the pile (without uplift due to water)
- Water in the pile

3.4 Berthing force

Table 3.4 Berthing Energy calculation

Vessel type	units	Small	Large
LNG tank volume	[m3]	70,000	210,000
Displacement at design/operational draught, wD	[tonne]	50,000	142,600
LOA (L)	[m]	205	310
LBP	[m]	195	300
Beam / Width of vessel, B	[m]	29	50
Design draught (Laden draught) (D)	[m]	10.5	12
Unit weight of water,w	[t/m]	1.025	1.025
Acceleration due to gravity,g	[m/sec2]	9.81	9.81
Berthing Velocity v	[m/s]	0.25	0.15
Mass coefficient (Cm)		1.36371	1.25188
I/r (For quarter point berthing)		1	1
Approach angle, ϴ	Degree	10	10
Eccentricity coefficient (Ce)		0.51	0.51
Softness coefficient (Cs)		0.95	0.95
Factor of Safety FoS		2	2
Berthing Energy with out factor of safety	t.m	105.237	99.1883
Berthing Energy with factor of safety	t.m	205.2	198.3766
Maximum % of energy absorption variation	%	10	10
Berthing Energy including variation	t.m	**225.73**	**218.2143**

3.5 Mooring force

The quick release hooks shall be provided with a Safe Working Load (SWL) of not less than the breaking load (MBL) of the largest rope anticipated to enable the handling of the mooring of the largest ship.
Breasting Dolphin
Mooring loads: 2 x 150 tonnes = 300 tonnes
Directions of mooring load: Combinations from guidelines given below
Horizontally: Parallel to berthing face from 10 to 45 degrees
Vertically: Up to 25 degrees above horizontal line
Mounting base shall be designed for 450 tonnes including FOS of 1.5.
Mooring Dolphin
Mooring load: 3 x 150 tonnes = 450 tonnes
Direction of mooring load: Combinations from guidelines given below
Horizontally: 45 degrees on either side from normal to berthing line
Vertically: Up to 25 degrees above horizontal line
Mounting base shall be designed for 675 tonnes including FOS of 1.5.

3.6 Temperature force

Temperature: Two different load cases shall be considered for 20° C temperature rise and fall

SERVICEABILITY CRITERIA

Deflection: The deflection criteria shall be so limited that it shall not produce difficulties in serviceability conditions nor shall it cause damage to the structures and pipelines supported on the approach, unloading platform and its components.
The horizontal deflection shall be checked for various load combinations of Table 10: Load

Combinations for limit state of serviceability and Table 11: Load combinations for limit state of serviceability & the maximum value shall be restricted as shown in below table.

Table 3.5 Horizontal deflection limits for various structures

TYPE OF STRUCTURE	OPERATING CONDITION (mm)	STORM/ SURGE CASE(mm)
Unloading Platform	110	130
Approach trestle	80	120
Mooring/Breasting Dolphins	115	160

Crack control

The structural elements shall be checked for crack width for operating load combinations in accordance with provisions of IS: 456-2000.

Crack width for final section with final loading shall be calculated and shall not exceed 0.2mm.

Crack width shall not be checked at top surface of super structure elements (i.e. Beams, deck slabs etc.) as the same can be easily accessible for maintenance, if required.

Current load

Current force on piles = $YDV^2/2g$ kN/m²

(cl. 5.6 IS 4651-part III)

4. RESULTS & CONCLUSIONS

4.1 COST OF CONSTRUCTION

4.1.1 BREASTING DOLPHIN

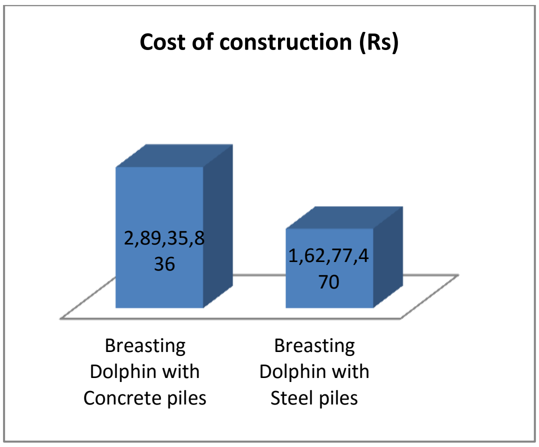

Fig 4.1 Cost of construction of Breasting Dolphin

4.1.2 MOORING DOLPHIN

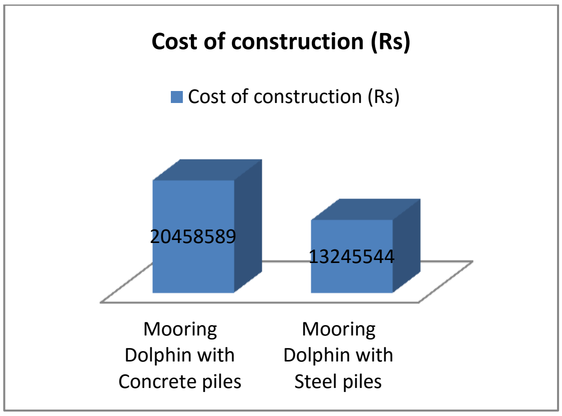

Fig 4.2 Cost of construction of Mooring Dolphin

4.1.3 UNLOADING PLATFORM

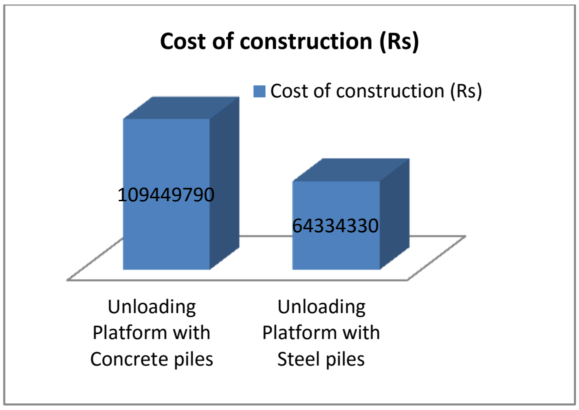

Fig 4.3 Cost of construction of Unloading platform

4.2 PILE DEFLECTION

4.2.1 BREASTING DOLPHIN

Piles	Deflection (mm)
Concrete piles	70.47
Steel piles	52.78

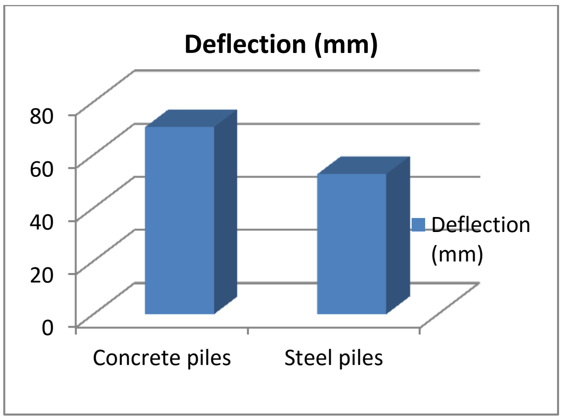

Fig 4.4 Pile deflection of Breasting Dolphin

Percentage of increase in deflection= 25.10%

4.2.2 MOORING DOLPHIN

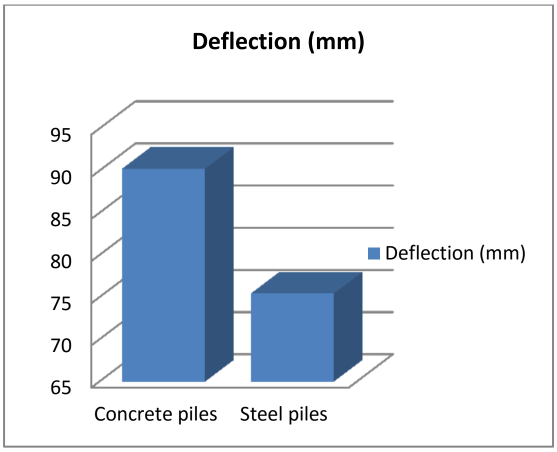

Fig 4.5 Pile deflection of Mooring Dolphin

Percentage of increase in deflection= 16.39%

4.2.3 UNLOADING PLATFORM

Piles	Deflection (mm)
Concrete piles	115.2
Steel piles	92.49

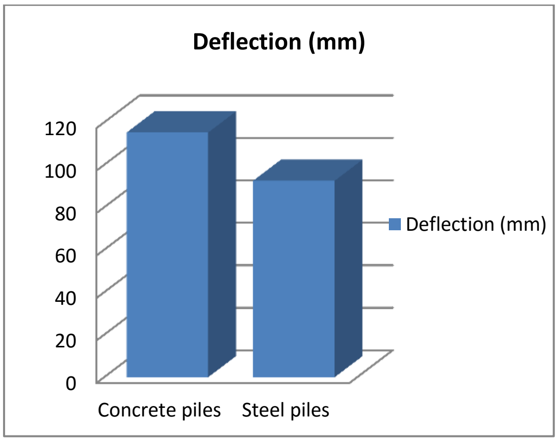

Fig 4.6 Pile deflection of Unloading Platform

Percentage of increase in deflection= 19.71%

4.3 CRACK WIDTH

4.3.1 BREASTING DOLPHIN

Crack width check for Top Reinforcement	0.208
Crack width check for Bottom Reinforcement	0.288

4.3.2 MOORING DOLPHIN

Crack width check for Top Reinforcement	0.259
Crack width check for Bottom Reinforcement	0.274

4.3.3 UNLOADING PLATFORM

Crack width check for Top Reinforcement	0.145mm
Crack width check for Bottom Reinforcement	0.268mm

Permissible crack width = 0.3mm

Since the crack widths are < 0.3 mm, Hence OK

4.4 CONCLUSIONS

From the results obtained the following conclusions arrived. For the given site location, for Unloading platform, Breasting Dolphin & Mooring Dolphins the cost of construction is 30– 45 % higher for structures with concrete piles compared to structures with steel piles. Pile defections are 25.10 %, 16.39%, 19.71% smaller for Breasting Dolphin, Mooring Dolphin and Unloading Platform with steel piles respectively compared to those structures with concrete piles. From the comparative study, it can be concluded that, marine structures with steel piles are the economical one.

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