Pushover Analysis of Pile Supported Wharf Structure in Vishakapatnam (India)

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Abstract. Wharfs and jetties are the key structures in port transportation systems that support export and import activities. Wharf structures during a seismic event are susceptible to severe damage and may have an adverse effect on port operations. Historical earthquakes such as 1995 Kobe earthquake (Mw = 6.9; Japan), 1999 Chi- Chi earthquake (Mw = 7.3; Taiwan) and 2004 the Great Indian ocean earthquake (Mw = 9.1; Sumatra) damaged major port structures, such as caissons, quays and pile-supported wharfs (Chiou et.al., 2011). These ports suffered severe economic losses due to the collapse of wharfs leading to downtime in port operations. This attracted the attention of researchers towards seismic analysis and design of port structures especially pile supported wharfs. In the present study a wharf structure from Vishakhapatnam port (Andhra Pradesh, India) has been chosen for pushover analysis. For the structural model of the pile supported wharf considered, shell elements were used for modelling the deck. Winkler model has been used for representation of the pile–soil system, in which the piles were represented by beam elements and soils were represented by springs. Pushover analysis has been carried out with distribution of lateral loads according to the fundamental modal shape of the wharf structure to derive the capacity curve of the wharf structure. Capacity spectrum method which is a nonlinear static procedure has been used to efficiently construct a response matrix of the wharf. Nonlinear static pushover analysis has been performed and it has been observed that the hinge sequence obtained for the wharf in transverse direction in the present study matches with the guidelines provided in PIANC.
Keywords: Pile foundation, wharf, capacity spectrum, push over analysis.

1 Introduction

Port transportation is one of the most important logistical systems, supporting universal movement of passengers and cargos cost effectively, thereby acting as a backbone for economic growth of country. In addition to playing a vital role in transporting people and cargos globally, ports and jetties play a crucial role in evacuating people and supplying relief materials before, during and after natural disasters when other transportation systems fail. A large numbers of important ports are located in active seismic regions worldwide. Rapid proliferation of international sea trade during last few decades has raised concerns about seismic safety of port structures. In India, nearly 95% of foreign trade by volume and 70% by value takes place through ports. Around 65% of country's land is under moderate to very high seismic risk, witnessing several major earthquakes at Bihar (1988), Uttarkashi (1991), Latur (1993), Jabalpur (1997), Chamoli (1999), Bhuj (2001), Sumatra (2004), Kashmir (2005), Nicobar islands (2005), Andaman islands (2009), Sikkim (2011), and Nepal (2015), indicating high frequency of earthquakes. Currently, there is no guideline for earthquake resistant design of port structures. The existing earthquake-resistant design standards IS 1893 and IS 13920 are proposed for buildings that behave very differently from port structures during earthquakes. So, in the absence of particular seismic design code for jetty and wharf structures, it becomes necessary to make vulnerability analysis of structure to understand its behavior and probability of failure (or probability of repair work after seismic hazard) for different intensity earthquake. A universal engineering practice to reduce seismic risk of port amenities is characteristically based on design or retrofit measures for distinct components articulated in terms of random levels of force and/or displacement. Seismic vulnerability analysis on the other hand provides a framework through which both economic issues and system performance can be taken into account and the performance of the port can be seen as a whole.

2 Site information

For the present study, a typical pile supported wharf at Vishakhapatnam port is selected. The port city Vishakhapatnam located in the south east coast of the country extends between $17^{o}40'$-$17^{o}45'$N latitudes and $83^{o}10'$-$82^{o}21'$E longitudes. The topography of Vishakhapatnam is undulated with hill ranges on three sides (Rao, 2007). Visakhapatnam city is in Intra plate region and falls under seismic zone II with a zone factor of 0.10g.The coast of Vishakhapatnam has been considered to be one of the weaker zones, where neo-tectonic activities were established in the recent past (Murthy and Subrahmanyam, 2012). Figure 1 shows the location map of the port considered in the present study.

3 Wharf layout and pushover analysis

The wharf is 560m long with 50mm expansion joint provided at every 50.64 m, 33.45m wide, and currently houses 150000 DWT container vessels. It consists of 10 individual units with 50 mm expansion joints provided every 50.64m, constructed with precast / in-situ RCC beams and deck supported on 45 bored cast in situ piles. The thickness of the deck is 0.5m; pile spacing is 4.0 m in the longitudinal direction and transverse direction.. The plan of the wharf structure considered has been shown in the Fig. 2.

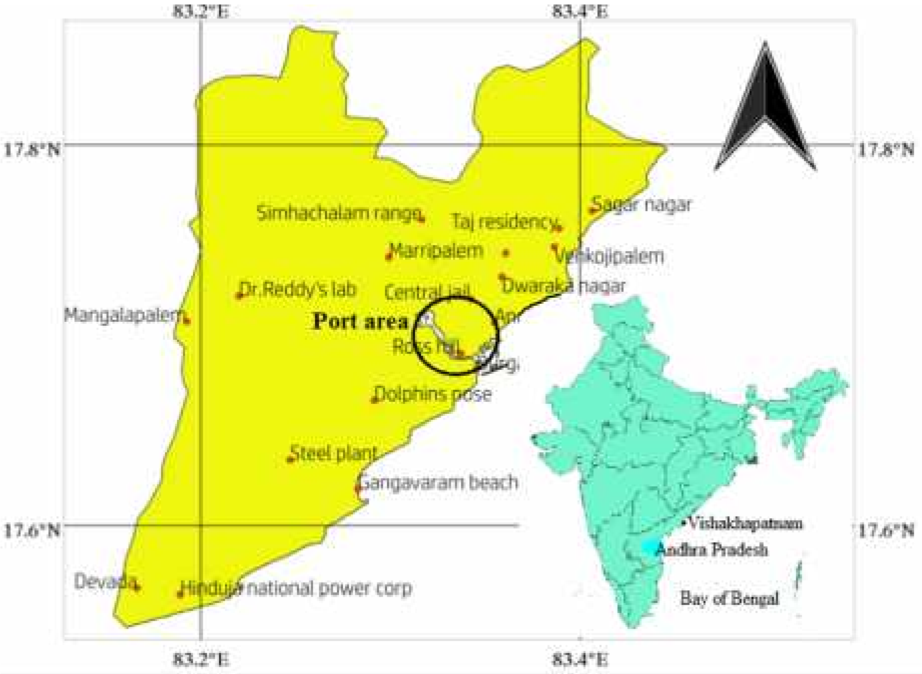

Figure 1: location map of the port (wharf structure)

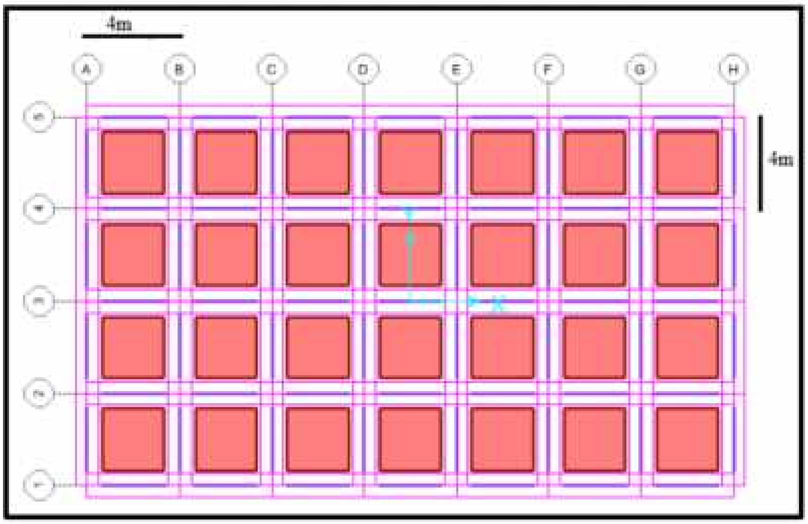

Figure 2: Plan of the Pile deck system designed against liquefaction

3.1 Analysis methods

For pile supported wharf PIANC recommends four methods for analysis of pile supported wharf

- Method A
- Method B
- Method C
- Method D

Method A is simplified analysis where in wharf tends to behave as a single degree of freedom structure under transverse response. Method B is multi-mode spectral analysis in which several piles in a line are lumped as a stand-alone element. This method is used in conjugation with pushover analysis. Method A and B are simplified analysis and hence can be used for preliminary design or low level of excitations. Method C is nonlinear static Pushover Analysis and method D is Time History Analysis where in different real time recorded accelerations along with soil-structure interaction are used to get structural response. As the performance grade increases, the level of analysis also increases. For the present study, method C has been adopted owing to time constraint and inaccessibility to high speed computer.

3.2 Geotechnical considerations:

There are two possible ways of considering the soil effect:

- Pile fixity depth consideration as per IS2911
- Calculating Winkler's spring constant and applying along the pile length by Newmark's distribution.

Pile fixity depth Intricate wave profile of laterally loaded pile can be simplified and represented as a vertical cantilever beam by establishing point of fixity correctly on it, in order to calculate lateral deflection. In the present study, pile fixity depth is calculated as per IS2911, wherein long flexible pile, either fully or partially embedded, is treated as a cantilever which is fixed at some depth below the ground level. Table 1 shows the final length of pile to be taken using fixity.

Table 1: Length of the pile using fixity method

Pile length	Final length of the pile (meters)
A	31.55
B	24.25
C	20.20
D	16.66
E	11.55

F	10.35
G	9.86
H	7.32

Numerical model preparation SAP 2000 is used to construct 3D model of the wharf as shown in Fig. 3. Beams and piles are modelled using frame element. Winkler model is used to represent soil structure interaction, wherein soil is symbolized by springs respectively. Linear springs are used for the study. Springs are distributed along the length of pile by Newmark‟s distribution. The time period of the structure according to IS1893 formula comes out to be 0.87 sec. (structure without infills). Pushover analysis of the wharf model is carried out in SAP 2000 to obtain its capacity curve.

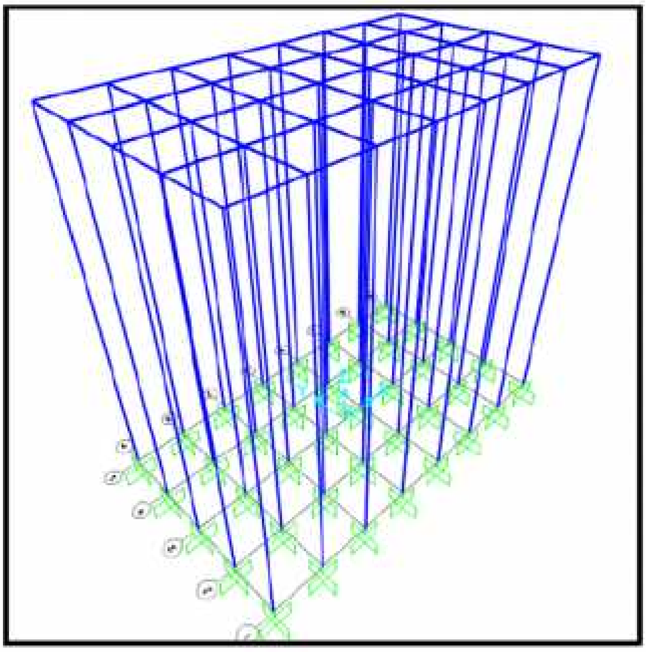

Figure 3: 3D model of the wharf structure from pushover analysis

Moment curvature relation and nonlinear hinge property Moment-curvature relation is the most important input parameter to carry out non-linear analysis of frame structures. It is a key tool for investigating deformation characteristics of piles in the wharf. It includes the effects of enhancement to concrete compression strength and ultimate compression strain capacity resulting from confinement provided by the spirals and differentiate between the unconfined cover concrete and the confined core. Nonlinear analysis requires evaluation of nonlinear hinge properties of each section in the structure, computed by strength and deformation capacities. In the present study, non-linear hinge properties of frame elements have been evaluated using section designer of SAP 2000 and have been assigned to the numerical model in SAP2000. It is concluded from the analysis that grid E piles are critical. The axial load taken by Grid E piles range between 0 kN to 3000 kN. Moment curvature relation for three axial loads i.e. 0 kN, 1500 kN and 3000 kN is derived for grid D piles using section designer of SAP 2000. Figure 4 shows the moment curvature plot up to whole section failure. Hinge properties are defined through the definition of the moment–curvature relation, plastic hinge length and an interaction surface, based on the guidelines of ATC40 and FEMA273.

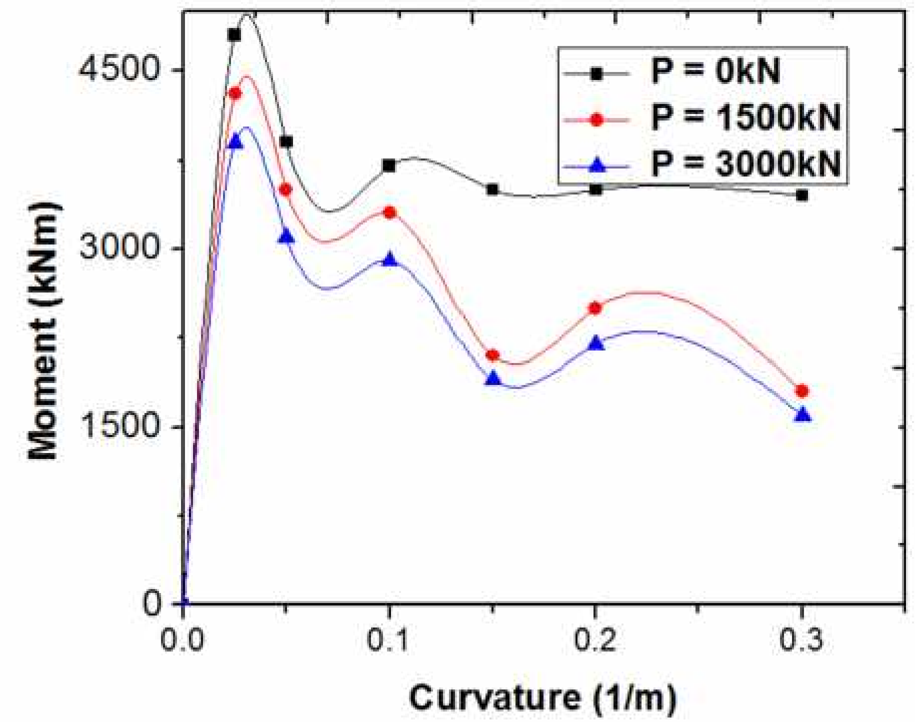

Figure 4: Moment curvature curves for grid D piles (whole section failure)

The multi piles in the selected structure fall under the category of long column. As long columns are vulnerable to axial-flexure failure, PMM hinges (P-M2-M3) are assigned to the pile sections at upper and lower ends. In piles, shear hinges are not assigned because the shear strength of concrete member with provided Ast is much more as compared to actual shear stress acting. To cross check, V3 hinges were assigned along with P-M2-M3 hinges to the piles but the governing failure mode was flexure. So, to reduce iteration process, only P-M2-M3 hinges are assigned to the piles.

Fragility means the quality of being easily broken or damaged. As the selected structure has multi piles (45 piles) supporting the deck of 50.64 m x 33.45 m, the case is more of checking vulnerability of piles. Beam failure is local whereas failure of even a single pile can make the entire structure unstable. Hence, to check effects of transfer of moment from beam to pile, beams were assigned with user defined flexural hinges at two ends (M3 hinges). Figure 5 shows a typical curve, defined by four points, displaying the property of distributed hinges. A is the origin, B is the crack point, C is the effective yield point, and D is the ultimate point.

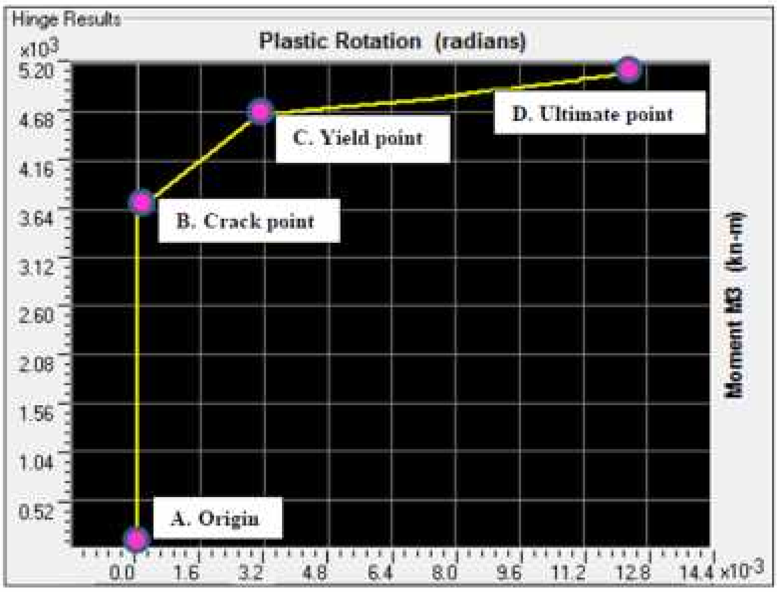

Figure 5: Property of one of the distributed hinges along grid E pile (SAP 2000)

Load application control Pushover analysis can be force-controlled or displacement-controlled. In force-controlled procedure, full load combination is applied and the capacity curve is constructed up to failure for lateral incremental load. In displacement-controlled procedure, specified displacements are known or determined (magnitude of applied load is not known in advance). The magnitude of load combination is increased or decreased until the control displacement reaches a specified value. In the present study, displacement control philosophy is used to construct the capacity curve.

Loading and direction The selected wharf has plan dimension of 50.64 m x 33.45 m. Also, the ground is sloppy in X direction, which calls for short column effect in grid E piles. In addition to these, there will be a governing effect of mooring and berthing forces in X direction. Hence, in the absence of particular load combination, incremental accelerating load in X direction is applied to the model, with initial stress condition as DL+0.5LL. It is assumed that during earthquake, only 50 % of live load is there on the deck.

Pushover curve and hinge formation sequence Nonlinear static pushover analysis is performed on the wharf. It also shows the hinge formation sequence at various stages, assigned as per ATC. The hinge sequence obtained for the wharf in transverse direction in the present study matches with PIANC. Pushover curve of the wharf is shown in Fig.6

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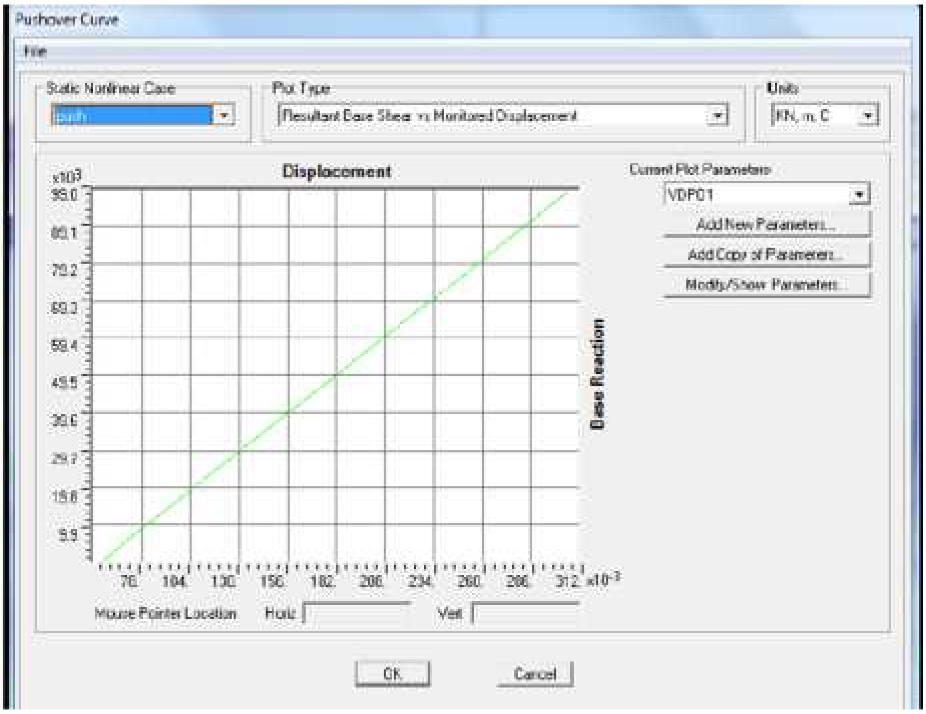

FIGURE 6: Pushover curve of existing wharf in SAP 2000

4 Conclusions:

Variation in bending moment values in piles, specifically grid D piles (critical), is observed using pile fixity depth and soil spring constant approach due to change in the fundamental time period of the structure and the corresponding base shear values. From the results of base shear and bending moment it has been observed that pile fixity depth analysis over estimates the design forces when compared to soil spring constant method. The pushover curve and hinge formation sequences that are obtained from the present study matches well with the design guide lines provided by PIANC. Such site specific studies will be further helpful in design as well as retrofitting of existing structures.

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