Design of Semi ? Flexible and Flexible Dolphins with Concrete Pile Caps

Vitaly B. Feygin

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Abstract

Introduction-In recent years, Port and marine industry design standards were shifting their focus towards performance based and elasto-plastic limit state design criteria. Whilst performance based criteria for wharves and piers were well explained and covered by POLA/POLB 1 , performance based design of the dolphins was never reviewed. Current PIANC WG-33 2 only briefly discussed design of the flexible dolphins. Some of the WG-33 statements related to fender supporting structures are ambiguous, and not well understood. In author' opinion, PIANC provisions do not differentiate between rigid, semi-flexible and flexible dolphin systems making conflicting statements. The following study covers several aspects associated with design of semi-flexible and flexible dolphin systems, and addresses design issues which were insufficiently covered by PIANC and national marine codes. The list of covered issues includes:? fender selection conflicts ? concept of impact dynamic amplification ? utilization of the ductility concept for performance based design criteria ? the concept of capacity protected elements and proper application of overload factors ? detailing mistakes in pile to pile cap connections.This paper reviews design of the flexible dolphin systems with concrete pile caps, explaining common design misconceptions and filling the gaps in the current design practice.

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1 Introduction

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? fender selection conflicts ? concept of impact dynamic amplification ? utilization of the ductility concept for performance based design criteria ? the concept of capacity protected elements and proper application of overload factors ? detailing mistakes in pile to pile cap connections.

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2 II.

3 Force of Abnormal Impact and

Fender Selection Clause 4.2.8.4(d) of PIANC WG-33 states: "It is considered advisable to check the supporting structure against failure for loads substantially greater, (of 2-3 times greater), than the reactions due to abnormal impact?" but does not explain the cause of magnification factor, and why force magnification is advisable?

This paper investigates two plausible sources of impact force magnification advisable by PIANC provision:

? Dynamic component of abnormal impact during the ? Ductility factor, µ D -requirement rooted in the performance based analysis.

The study was structured as a step by step approach:

Effect of the ductility factor component of the magnification coefficient, k cm , was analyzed in section III, and an investigation of the dynamic component of abnormal impact was reviewed in Section IIa, following review of the fender selection (Example 1). Example 1. Fender Selection for Rigid Dolphin Fender selection and analysis of forces acting on a rigid dolphin during abnormal berthing impact are explained below. All denominations used in this analysis correspond to denominations of PIANC WG-33. Compliance with both methods is achieved by applying a correction multiplier K R = L.F. / C AB to Abnormal Berthing Reaction R AB .

Correction factor K R preserves fender size based on Abnormal Impact Energy requirements of PIANC WG-33 and complies with Limit State Load Factors set by national marine standards.

In the studied project, the Limit State Load factor was based on a wrong interpretation of AS 4997, cl. 5.3.2.5. As a result, selected ultimate limit state reaction corresponding to abnormal impact applied to the breasting dolphin was overestimated by 25%.

Another design issue frequently yielding conflicting results is related to a proper selection of the Thus, C for the smallest vessel can be determined from the following formula: C' AB smallest = C AB largest vessel * (m smallest vessel /m largest vessel) * (V smallest vessel / V largest vessel) 2 (Formula 1) but shall be restricted by the following boundaries: C' AB smallest < C AB smallest as given by PIANC WG-33, Table 4.2.5 (The above formulas shall be used for similar types of vessels only and should not be applied when the same dolphin is utilized for the berthing of dissimilar vessels like tankers and general cargo carriers, etc. Such an arrangements shall be avoided, anyway). PIANC WG-33, Cl. 4.2.8.5 clearly states that Table 4.2.5 shall be used as a general guidance only, and the "designers' judgment should be paramount in determining the appropriate factor".

All of the above relates to the fender selection for rigid dolphin structures.

Fender selection process for semi-flexible and flexible dolphins is slightly different.

The following discussion requires a clear explanation of the differences between Semi-Flexible and Flexible Dolphin systems.

In accordance with PIANC, flexible dolphin consists of vertical or near vertical piles cantilevered from the waterbed, and such dolphin system absorbs berthing energy via horizontal deflection of the pile heads under the berthing impact.

The group of dolphins described above includes both semi-flexible and flexible dolphin systems.

Comment 2, below, explains the difference between two subgroups.

4 Comment 2:

Semi-flexible dolphin consist of a group of vertical or near vertical piles cantilevered from the waterbed and designed to absorb the energy of impact by horizontal deflection within the elastic boundaries where dolphin pile sections do not undergo elastoplastic deformations.

Flexible dolphins having similar construction features are designed as ductile structures with elastoplastic deformations within the pile sections. Piles in such dolphins undergo partial plastification and allow residual inelastic deformation of the dolphin.

The following example explains conceptual design of the Flexible Dolphin System. Example 1A. Fender Selection for Semi-Flexible and Flexible Dolphins.

Step 1. Start with the assumption that between 15% and 20% of abnormal impact energy is absorbed by elastic or elasto-plastic deformations of the dolphin structure itself. Validity of that assumption will require verification.

Step 2. Ignore manufacturing composite factors for energy absorption, and select fender based on E' AB = E O * C AB = 2,268kN-m; hence, fender size can be dropped from SCN2000E0.9 to SCN1800E1.2 Frequently, the owner dictates the largest C ABfactor from WG-33, Table 4.2.5 (CAB=2.0).

It shall be understood that selection of a stiffer fender penalizes the dolphin structure for no reason and defeats the purpose of the rubber fender, in a first place. Such definitions as "largest" or "smallest" vessel (WG-33, Table 4.2.5) are frequently misinterpreted. Erroneously, the difference in C AB -factors for largest and smallest vessels may be as high as 40%.

However, C AB is a composite energy factor directly proportional to the vessel composite mass (m), and square power of the approaching berthing speed, V 2 .

Since the approaching speed (vector of the approaching speed is normal to the berthing key line) of largest and smallest vessels may be identical, C AB variation will depend on a mass ratio of both vessels. Table **??** shows analysis of the impact impulse length (?) for a rigid dolphin system in a tabular format.

abs deflection) is equal to about 75% of the rated reaction, , of the selected fender.

From Table **??**, maximum rated reaction, R R =2,476 kN occurs at 0.63m fender deflection or 1.8m?0.63m=1.17m standoff.

A similar analysis was done for a flexible dolphin system. Results of that analysis are summarized in Table **??**.

The flexible dolphin of the studied case was constructed of four 1500 mm O.D. pipe piles with a 25 mm thick wall. Corrosion allowance for pipe piles 3 m below the mud line and above was taken as 6mm. Table **??** shows energy absorption capacity of the system at every force increment. At every instance, the force acting on the rubber fender is reacted by the dolphin, and both deflections shown in Table **??** and Figure 1 contribute to energy absorption of the semi-flexible or flexible dolphin system.

Figure 1 shows Buckling Fender Reaction-Deflection curves of the flexible dolphin structure, where deflection of the fender is shown with sign (+) and deflection of the dolphin is shown with sign (?) for the purpose of convenience only. The algebraic sign has no physical meaning in the presented graph. Energy absorbed by the rubber fender and dolphin structure can be estimated by integrating area under the curves.

Analysis of the impulse length (Rubber Fender + Flexible Dolphin) Table **??** : R R Reaction-deflection curve of the fender can be closely fit by a polynomial curve generated by Excel. Using Excel's trend line option, designer can derive the formula for the curve and calculate fender energy absorption by integrating area under the curve within the deflection range. Investigation of the possible Dynamic Amplification based on the fender data presented in the Table **??** is presented below: Dynamic Magnification, is normally applied to the initial impact force. P-y curve of the rubber fender (Figure 1) indicates that during the ship contact with the fender, system experiences impact impulse twice:

? Primary impact during initial contact, and ? Secondary impact at 67% of the fender standoff (after fender buckling, at about 40% of the initial fender standoff.) However, results of the fender compression analysis consolidated in Table **??** indicate that the system absorbs all Kinetic Energy of impact at about 67% of the original fender height or 0.67*1.80 = 1.20m standoff.

Summary of Impact Force magnification is shown in Figures **??**A and 3B The nature of the fender buckling negates any possibility of dynamic impact magnification unless proposed fender was improperly selected, or was very stiff. That statement is true for rigid dolphins.

Flexible dolphins have another line of defense against dynamic impact amplification: dolphin deflection itself.

5 Comment 3:

A summary of impact magnification analysis shown in Table 3 indicates that flexible dolphin protected by a rubber fender does not experience dynamic impact amplification. The graph presented in Figure 1 indicates that dynamic amplification becomes a strong possibility only in rigid dolphin systems when the fender was underrated and deflected beyond the point of specified maximum deflection, or was overrated and had not buckled.

In the Rigid Dolphin case, energy is absorbed entirely by the rubber fender deflection, requiring a larger-sized fender; whereas in the Flexible Dolphin case, about 20% of the kinetic energy is absorbed by the flexible dolphin structure itself. That allows selection of the smaller and softer fender.

An additional energy absorption mechanism based on plastic deformation of the flexible dolphin is Benefits of the Flexible Dolphin system become clear after comparison of torsional effects of the tangential force for both rigid and flexible systems (

6 Structural Design of the Flexible Dolphin

Analysis of dolphin plastic deformations (performance based design criteria) requires design philosophy utilizing and defining special members known as "Capacity Protected Elements." The term "Capacity Protected Elements" was first introduced by were never fully explained.

7 Comment 4:

An element shall be treated as Capacity Protected when elastic failure of the element changes the boundary condition of support or critical connection.

That concept was vaguely discussed by PIANC WG-33, clause 6.6.4: "The following load factors for the limit state design method are advised? depending on the pile capacity to resist overloads by plastic yielding.

? No yielding possible, ? = 1.25

? Yielding possible until a displacement of at least two times the maximum elastic displacement, ? = 1.00 " Rewriting PIANC statement: "The following load factors for the limit state design method are advised? depending on the pile capacity to resist overloads by plastic yielding:

? Pile to pile cap connection detail yields prior to yielding of dolphin piles, ? = 1.25

? For Piles undergoing elasto-plastic deformations which are less than twice the elastic deflection based on gross moment of inertia of the affected piles, overload factor ? shall be interpolated utilizing V o pile = 2 * M o pile / L c (**Formula 5)**

Where, M p -pile plastic moment capacity, at the location of the first plastic hinge.

If the shear plug was designed as a composite reinforced concrete section, it is expected that the first plastic hinge will develop at, or slightly below, the soffit of the pile cap.

L c -the distance between maximum moments in the pile (distance between the pile cap soffit and point of pile virtual fixity) Modified forces shall be used for the design of the Capacity Protected Elements within the pile cap. Such elements related to the pile-to-pile cap connection detail comprise: ©

8 t(hickness) = R-r

Step 2. Define the angle between the neutral axis and the edge of the slice, (?), as shown in Fig. 4 Step 3. Define chords confined by a small increment d?:

Exterior and interior archs of the pipe confined by d? can be approximated by a chord length, R * d(?) (Formula 6) r * d(?) (Formula 7)

Step 4. Calculate area of the pipe shell confined by d (?):dA i = 1/2 * (R+r) * t * d(?) (Formula 8)

Step 5. Define the distance from the neutral axis to the elementary area,y ? = y? = 1/2 * (R+r) * sin(?) (Formula 9)

Step 6. Calculate moment of inertia of the pipe section confined by the central angle (?) in each of the 4 quadrants,) (*) (sin * *) 2 /) ((2 2 2 3 2 ? ? ? + = = ? ? ? a i i eff d t r R dA y I I eff = 1/4 * (R+r) 3 * t * [0.5 * ? -0.25 * sin2(?)

] over integration limits (Formula 10) For checking formula, set integration limits between (?/2) and (-?/2) for fully elastic section: For checking formula, set integration limits between (?/2) and (0) for fully plastic section.I ? =I a eff =

Z ? = (R+r) 2 * t (fully plastic section)(Formula 15)

Moment taken by a plastisized portion of the section (Formula 16)

Step 11. Total moment capacity of the section is described by Formula 17 (Formula 17)

Step 11 concludes analysis of partially plastisized pipe section.

Compliance with clause 6.6.4 of PIANC WG-33: "deflection equal to 2 times elastic deflection," requires at least part of the pipe section to be in a plastic mode, thus reducing the effective moment of inertia of the pile section to the level where the elasto-plastic section deflects twice the magnitude of initial elastic displacement. The new moment of inertia for such section is defined by Formula 10.

Figure 5 Equating the work done by the hypothetical external force (H) to the energy absorbed by the dolphin:H * ? du = 0.5H p * ? de + H p * (? du -? de) (Formula19)

Where, H * ? du ? is work done by a hypothetical impact force (H) 0.5H p * ? de + H p * (? du -? de) ? Energy absorbed by a dolphin prior to being forced into instability. Rewriting Formula 19 in terms of H p /H:H p / H = 2µ D / (2µ D -1) (Formula 20)

Formula 20 establishes the relationship between Dolphin Capacity (H p) and Demand Load (H), Where H is the maximum anticipated load.

It should be understood that ductility factor applies only to flexible dolphins, but does not have any physical meaning for semi-flexible systems exhibiting fully elastic behavior.

9 Comment 6:

A ductility factor of µ D < 3 shall be used as a target for flexible dolphin design. Ductility factors in that range allow the structure to be in continual use while undergoing insignificant structural repairs.

A ductility factor of 4 < µ D < 7 defines damage criteria associated with moderate damage to the dolphin structure. However, certain design limitations shall apply:

? Design shall rely on plastic deformations of the pile material, but not on elasto-plastic deformations of the soil.

? Pipe pile shall not be subjected to ovalization and/or buckling.

? Residual plastic deflection should not be excessive. Accordingly, the dolphin will experience, not a minor, but, a moderate distress which will require a longer time down for remediation repair.

In performance based design criteria, it is important to know the residual deflection of the system. That parameter allows engineer to determine projected useful life of the structure.

Residual plastic displacement of the system can be estimated from the following equation,? res = ? I eff -? I gross ,

Where, ? I eff -deflection based on effective moment of inertia of elasto-plastic section determined from Formula 10 ? I gross -deflection based on moment of inertia of fully elastic section. The concept of a point of virtual fixity shall be further explained, since frequently this point is determined incorrectly.

Iterating on angle (?) (Formula 10), designer can determine: a) an elasto-plastic section satisfying the factored moment demand (M u =11,497kN); b) calculate effective moment of inertia (I eff); c) estimate additional elastic displacement associated with I eff , based on energy absorption requirements Comment 9: Clause 4.2.8.4(d) of PIANC WG-33 requires design of the fender supporting structure for a force of 2 (µ D =1) to 3 times (µ D =0.75) greater than the force of abnormal impact.

Review of such requirement indicates that it lays outside of performance based criteria promoting rigid to semi -flexible dolphins rather than flexible dolphins with residual plastic deformations.

Table **??** provides good correlations between ductility factor µ D and ratio of Dolphin Capacity (H p) and Demand Load (H)

The data presented in Table **??** explains Clause 4.2.8.4(d), but also indicates that a good design practice should target fully elastic semi-flexible dolphin system. Residual plastic deformation of the dolphin, ? res = ? I eff -? I gross = 0.56 -0.38 = 0.18m Calculated residual deflection is excessive. Study of the case indicates that dolphin was designed as a Flexible system, and therefore will have a fairly short useful life considering magnitude of the residual deflection.

Utilizing the graph shown in Figure 7, engineer can find overload factor (? =1.12) utilized for analysis of the Capacity Protected Elements within the pile cap.

10 The forces

M o pile = ? * M pile = 1.12M pile =11,497 * 1.12 = 12,071kN-m (? =1.12, See Figure 7) A stiffer dolphin structure will require more robust pile-to-pile cap connection detail and may shift the system into the rigid dolphin category, while softer system will push dolphin into the flexible design category. Both, rigid and flexible dolphins present extreme and hardly rational design cases. Rational design shall be based on semi-flexible dolphin system philosophy.

? Pile-to-Concrete Pile Cap connection design Figures 2 and 3 show pile cap failure zones developing as a result of ”shear plug” prying action caused by the pile rotation. Rotation of the shear plug and its rigidity impose heavy reaction forces against the confining bands (Figures 2A and 2B). Sensitivity of the pile-to-pile cap connection detail becomes obvious if it is viewed as an inverted pile embedded into a rigid medium. 7 The detail should be modeled as a short beam on an elastic foundation utilizing a two-point p-y curve of soft rock as a substitution for a concrete p-y curve.

Pile-to-pile cap connection detail (Figures 2 and 3 Therefore, the shear plug confinement band shall be designed for the restraining of shear plug rotation. ? Bottom confinement band model R bot spr = 9,029kN M bot = 12,493kN-m EFR = 7,641kN/m F y = 551MPa (ASTM A706 high strength mild steel) Area of the primary lower band reinforcement was calculated as A bot s = R bot spr / 0.9*F y = 9,029*10 3 / (0.9*551) = 18,207mm 2

Effective width of the shear plug (1.2m) was determined from the shear plug geometry. Therefore, bearing stress under the shear plug f brg = 8,455kN / (1.2*1.0) = 7.05MPa < 0.85*35MPa = 30MPa Confinement band reinforcement shall be placed as compactly as possible, placing 4 leg bands in one layer when possible.

Comment 11:

Based on Design Memorandum of WSDoT (February 14, 2012), ASTM A706 Grade 80 steel (Fy =80 ksi or 551MPa) may be used for elements not experiencing inelastic deformations. Grade 80 reinforcement steel can be effectively utilized for design and detailing of capacity protected elements experiencing tensile forces only.

It shall be noted that Figures 8 and 10 show a constant slope and, as a result, exaggerated deflection of the pile shear plug. It is considered prudent and conservative to artificially increase stiffness of the pile shear plug until it starts behaving as a short, stiff beam on an elastic foundation. Such an approach yields slightly conservative results for the magnitude of the reaction force resisted by Capacity Protected Elements (confining However, for investigation of the concrete crushing and plug deflection, designer shall use the real stiffness of the pile shear plug.

Size of the secondary confinement reinforcement, in the direction perpendicular to the primary confinement, can be determined from the ratio of secondary force (force parallel to the fender face panel) to force acting during abnormal berthing impact.

Analysis of the path of resistance not only requires proper of the analytical problem, but also selection of the proper modeling technique. In the studied case, the engineer utilized the Strut-and-Tie model for the of Pile-to-Pile cap connection analysis. However, comparison of the analytical model and on the design drawings incompatibility between analysis and detailing.

As a result, lever arm between forces of the resisting couple was grossly overestimated, leading to a 20% deficiency in area of confining band reinforcement.

Several critical discussed below, outline conditions necessary for compatibility between analytical and design details of the Pile-to-Pile cap connection.

11 Comment

? Confining Band in tension should not be modeled as a pin support. Note: Confining band acts as a spring, when subjected to a Direct Tension Force (DTF). Length of the spring shall be taken as a distance between confining band lateral supports. Lateral supports must support band in both orthogonal directions. ? Depending on pile position in relation to the force direction, the spring band support should be applied at the top or bottom of the shear plug, but never at both locations. When band is reinforced similarly to a concrete column where ties confine longitudinal and provide direct bearing support a shear plug, detailing may allow modeling of the confining band in the compression zone as a pin support. Nevertheless, utilization of the Strut-and-Tie model requires additional reinforcement detail: tying top and bottom confining bands with evenly spaced vertical closed stirrups. ? Where design and detailing do not satisfy bullet (2) of Comments, tension spring support shall be coupled with compression E(lastic) (F)oundation (R)eaction of the concrete medium.

Today, in a team work environment, analytical models and detailing are frequently poorly coordinated. Model-design incompatibility happens more often than it could be anticipated.

The Strut-and-Tie model requires special detailing, and there are certain geometrical limits when special detailing becomes economically unviable (particularly when pile diameter exceeds 762 mm).

Another serious omission in the design of the pile-to-pile cap connection is frequently related to detailing of the pile embedment where the designer leaves dowels of the shear plug (within the depth of the pile cap) without spiral or tie confinement.

Such an omission leads to a deficient boundary condition of the shear plug itself, changing fixed connection to a partial fixity with significant rotational

12 Summary of the Connection

Detailing Requirements

? Pipe pile shall be extended into the pile cap to the full height of the cap, or alternatively, dowels of the shear plug embedded into the concrete pile cap shall be always confined by a spiral with a pitch not greater than 150mm.

? Shear plug dowels confinement is necessitated by stiffness requirements of the shear in a short pile failure mode. Spiral volumetric ratio and spiral pitch shall be determined from formulas provided by CALTRAN.

? Confinement reinforcement shall run in orthogonal directions shown in Figure **??**.

? Confinement reinforcement shall be designed with stirrups or ties preventing excessive de-bonding during potential concrete spall. Such ties must be spaced not wider than 600 mm c/c

? Secondary confinement reinforcement does not need to be larger than 20% of the area of primary reinforcement for berthing dolphins. For mooring dolphins, area of primary and secondary confinement will depend on angular positions of the mooring lines.

VII.

13 Summary of the Case Study

Review of the case indicates that while a flexible dolphin solution presents a viable alternative solution to a rigid dolphin system, the engineer should aim for the design of a semi-flexible system exhibiting both elastic behavior and the ability to absorb kinetic energy of impact into a sizable deflection in the dolphin structure. [1] [2]

Figure 1: (E

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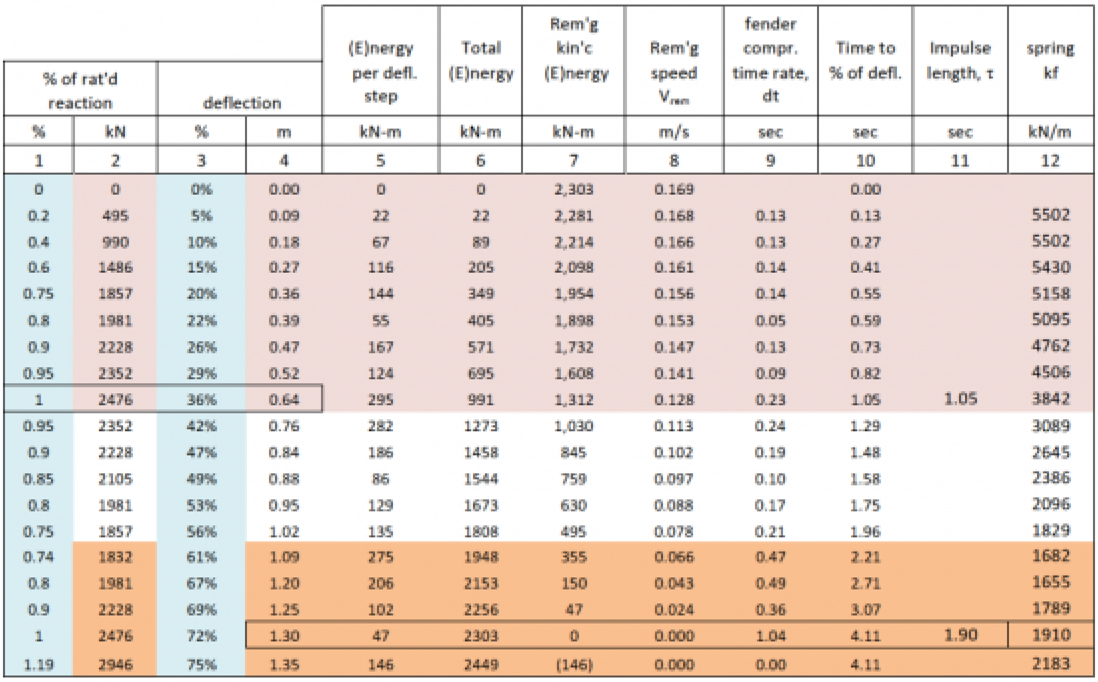
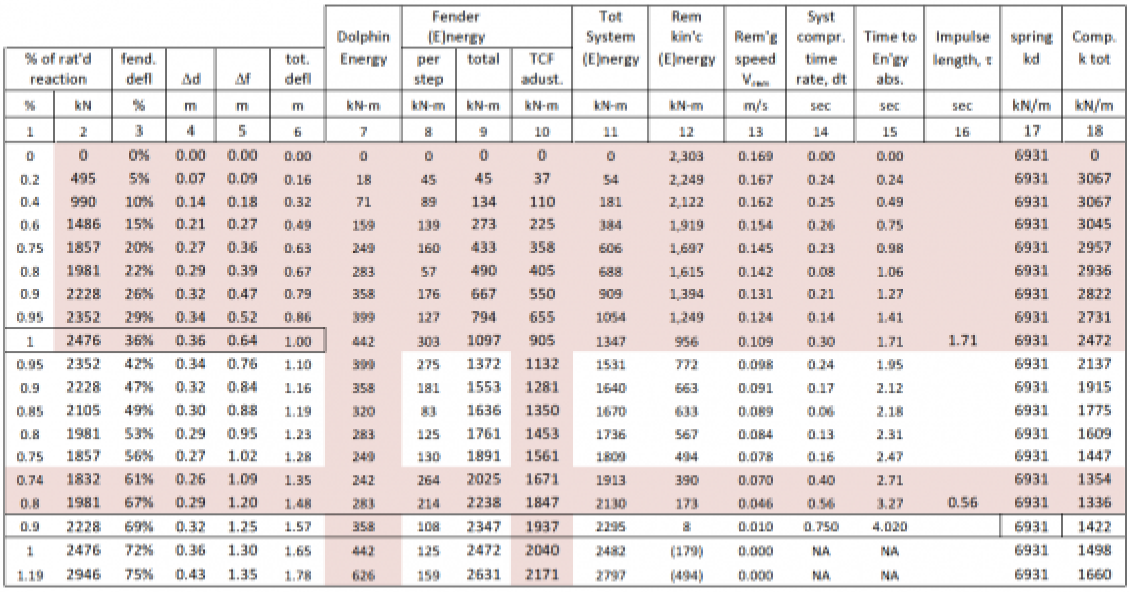
[1] © 2015 Global Journals Inc. (US)

[2] Year 2015 E Design of Semi ? Flexible and Flexible Dolphins with Concrete Pile Caps



% of rat'd reaction		deflection		(E)nergy per defl. step	Total (E)nergy	Rem'g kin'c (E)nergy	Rem'g speed V_{rem}	fender compr. time rate, dt	Time to % of defl.	Impulse length, τ	spring kf
%	kN	%	m	kN-m	kN-m	kN-m	m/s	sec	sec	sec	kN/m
1	2	3	4	5	6	7	8	9	10	11	12
0	0	0%	0.00	0	0	2,303	0.169		0.00		
0.2	495	5%	0.09	22	22	2,281	0.168	0.13	0.13		5502
0.4	990	10%	0.18	67	89	2,214	0.166	0.13	0.27		5502
0.6	1486	15%	0.27	116	205	2,098	0.161	0.14	0.41		5430
0.75	1857	20%	0.36	144	349	1,954	0.156	0.14	0.55		5158
0.8	1981	22%	0.39	55	405	1,898	0.153	0.05	0.59		5095
0.9	2228	26%	0.47	167	571	1,732	0.147	0.13	0.73		4762
0.95	2352	29%	0.52	124	695	1,608	0.141	0.09	0.82		4506
1	2476	36%	0.64	295	991	1,312	0.128	0.23	1.05	1.05	3842
0.95	2352	42%	0.76	282	1273	1,030	0.113	0.24	1.29		3089
0.9	2228	47%	0.84	186	1458	845	0.102	0.19	1.48		2645
0.85	2105	49%	0.88	86	1544	759	0.097	0.10	1.58		2386
0.8	1981	53%	0.95	129	1673	630	0.088	0.17	1.75		2096
0.75	1857	56%	1.02	135	1808	495	0.078	0.21	1.96		1829
0.74	1832	61%	1.09	275	1948	355	0.066	0.47	2.21		1682
0.8	1981	67%	1.20	206	2153	150	0.043	0.49	2.71		1655
0.9	2228	69%	1.25	102	2256	47	0.024	0.36	3.07		1789
1	2476	72%	1.30	47	2303	0	0.000	1.04	4.11	1.90	1910
1.19	2946	75%	1.35	146	2449	(146)	0.000	0.00	4.11		2183

Figure 2:



% of rat'd reaction		fend. defl	Δd	Δf	tot. defl	Dolphin Energy	Fender (E)nergy			Tot System (E)nergy	Rem kin'c (E)nergy	Rem'g speed V_{rem}	Syst compr. time rate, dt	Time to En'gy abs.	Impulse length, τ	spring kd	Comp. k tot
							per step	total	TCF adust.								
%	kN	%	m	m	m	kN-m	kN-m	kN-m	kN-m	kN-m	kN-m	m/s	sec	sec	sec	kN/m	kN/m
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	0	0%	0.00	0.00	0.00	0	0	0	0	0	2,303	0.169	0.00	0.00		6931	0
0.2	495	5%	0.07	0.09	0.16	18	45	45	37	54	2,249	0.167	0.24	0.24		6931	3067
0.4	990	10%	0.14	0.18	0.32	71	89	134	110	181	2,122	0.162	0.25	0.49		6931	3067
0.6	1486	15%	0.21	0.27	0.49	159	139	273	225	384	1,919	0.154	0.26	0.75		6931	3045
0.75	1857	20%	0.27	0.36	0.63	249	160	433	358	606	1,697	0.145	0.23	0.98		6931	2957
0.8	1981	22%	0.29	0.39	0.67	283	57	490	405	688	1,615	0.142	0.08	1.06		6931	2936
0.9	2228	26%	0.32	0.47	0.79	358	176	667	550	909	1,394	0.131	0.21	1.27		6931	2822
0.95	2352	29%	0.34	0.52	0.86	399	127	794	655	1054	1,249	0.124	0.14	1.41		6931	2731
1	2476	36%	0.36	0.64	1.00	442	303	1097	905	1347	956	0.109	0.30	1.71	1.71	6931	2472
0.95	2352	42%	0.34	0.76	1.10	399	275	1372	1132	1531	772	0.098	0.24	1.95		6931	2137
0.9	2228	47%	0.32	0.84	1.16	358	181	1553	1281	1640	663	0.091	0.17	2.12		6931	1915
0.85	2105	49%	0.30	0.88	1.19	320	83	1636	1350	1670	633	0.089	0.06	2.18		6931	1775
0.8	1981	53%	0.29	0.95	1.23	283	125	1761	1453	1736	567	0.084	0.13	2.31		6931	1609
0.75	1857	56%	0.27	1.02	1.28	249	130	1891	1561	1809	494	0.078	0.16	2.47		6931	1447
0.74	1832	61%	0.26	1.09	1.35	242	264	2025	1671	1913	390	0.070	0.40	2.71		6931	1354
0.8	1981	67%	0.29	1.20	1.48	283	214	2238	1847	2130	173	0.046	0.56	3.27	0.56	6931	1336
0.9	2228	69%	0.32	1.25	1.57	358	108	2347	1937	2295	8	0.010	0.750	4.020		6931	1422
1	2476	72%	0.36	1.30	1.65	442	125	2472	2040	2482	(179)	0.000	NA	NA		6931	1498
1.19	2946	75%	0.43	1.35	1.78	626	159	2631	2171	2797	(494)	0.000	NA	NA		6931	1660

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Figure 3: Step 3 . 2 (3 2015 E

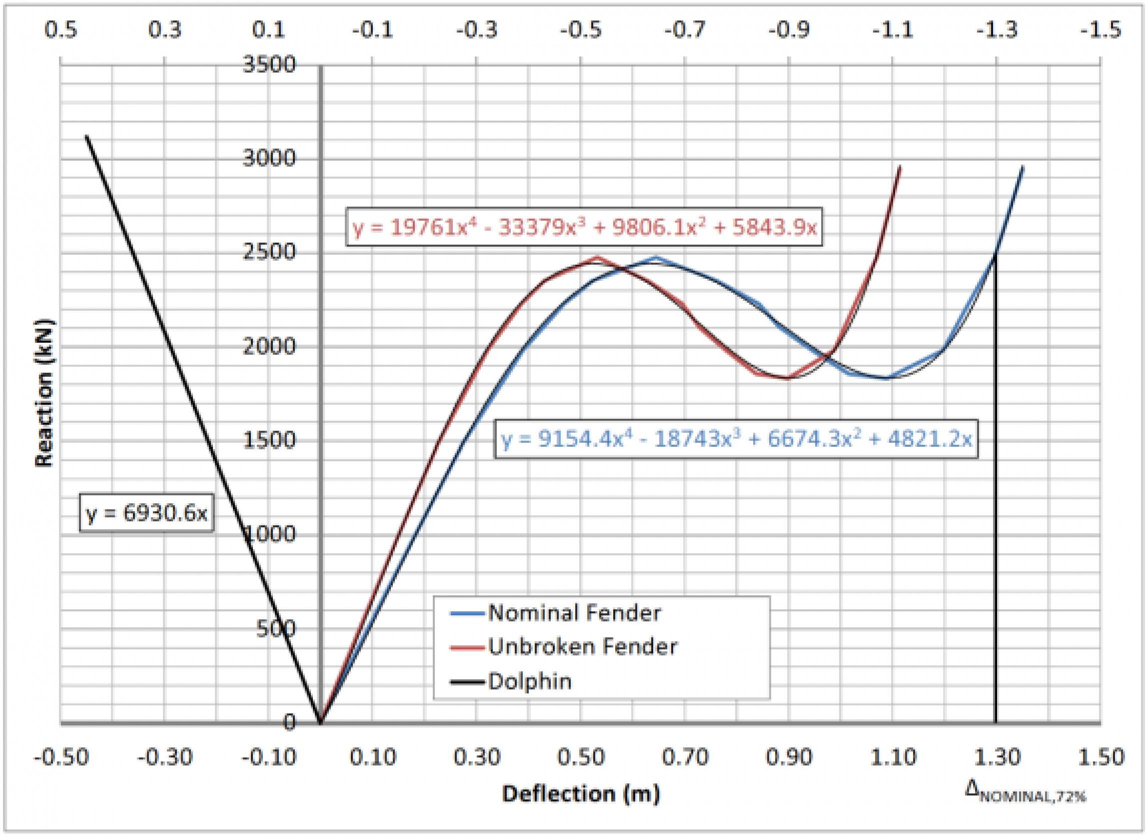

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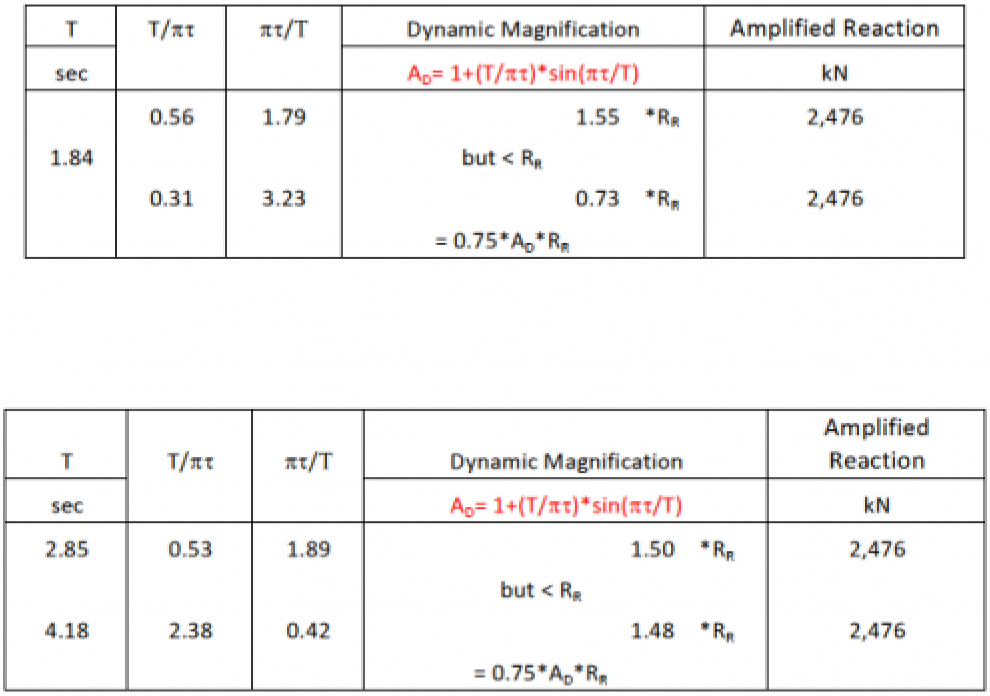
Figure 4: Step 2 . 4 Ee



T	T/πτ	πτ/T	Dynamic Magnification	Amplified Reaction
sec			$A_D = 1+(T/\pi\tau)*\sin(\pi\tau/T)$	kN
1.84	0.56	1.79	1.55 $*R_R$	2,476
			but < R_R	
	0.31	3.23	0.73 $*R_R$	2,476
			= $0.75*A_D*R_R$	

T	T/πτ	πτ/T	Dynamic Magnification	Amplified Reaction
sec			$A_D = 1+(T/\pi\tau)*\sin(\pi\tau/T)$	kN
2.85	0.53	1.89	1.50 $*R_R$	2,476
			but < R_R	
4.18	2.38	0.42	1.48 $*R_R$	2,476
			= $0.75*A_D*R_R$	

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Figure 5: 5 2015 E

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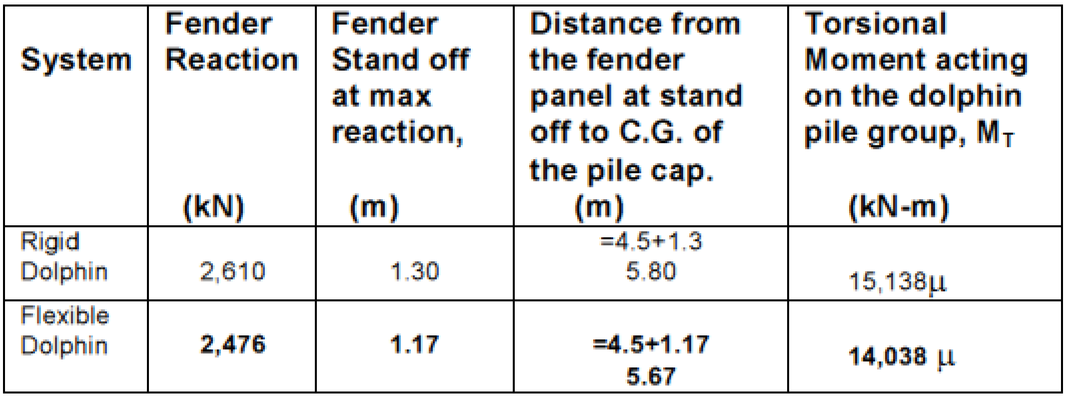

System	Fender Reaction (kN)	Fender Stand off at max reaction, (m)	Distance from the fender panel at stand off to C.G. of the pile cap. (m)	Torsional Moment acting on the dolphin pile group, M_T (kN-m)
Rigid Dolphin	2,610	1.30	=4.5+1.3 5.80	15,138μ
Flexible Dolphin	**2,476**	**1.17**	**=4.5+1.17** **5.67**	**14,038 μ**

Figure 6: 6 Ee

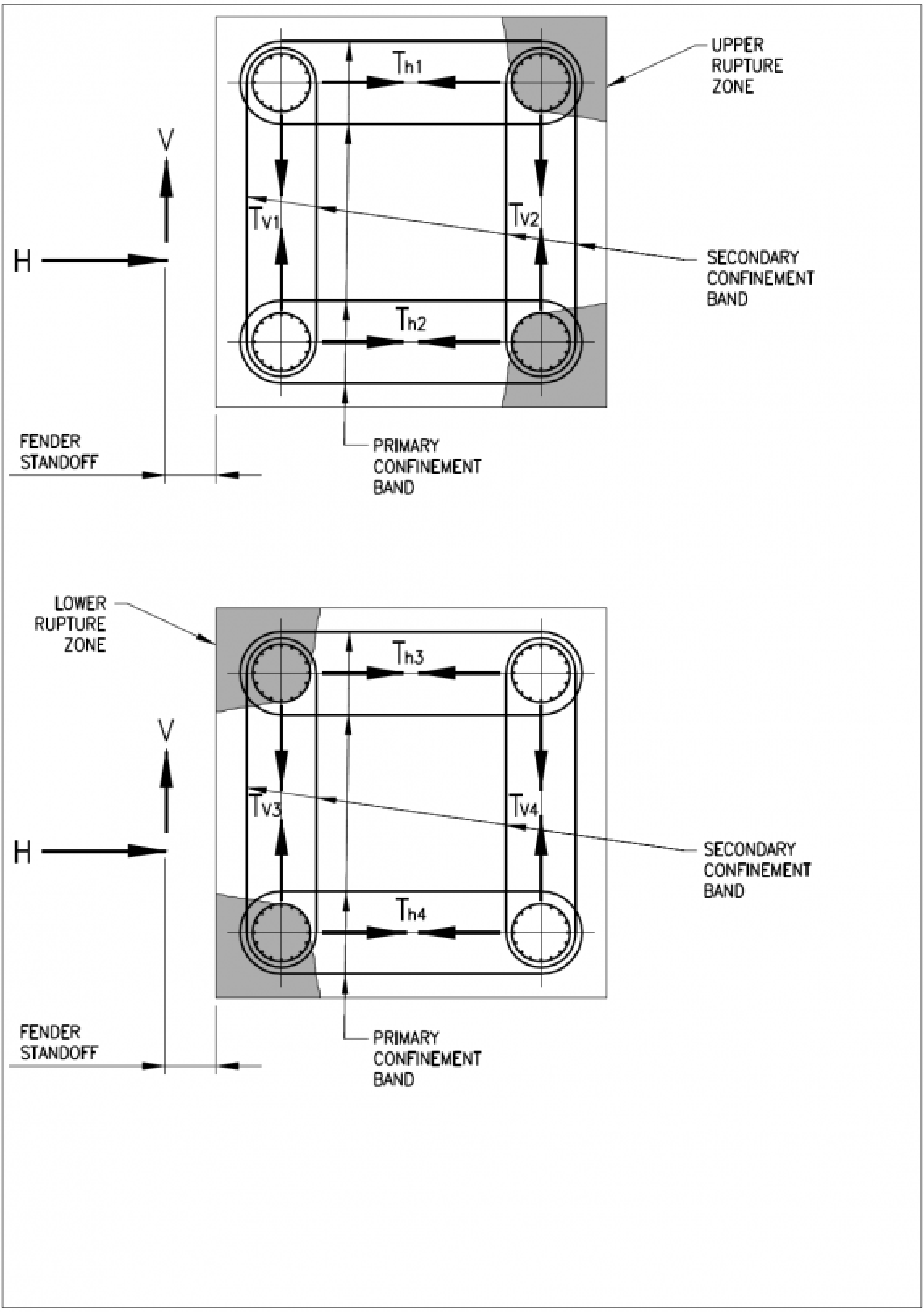

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Figure 7: Figure 1 :

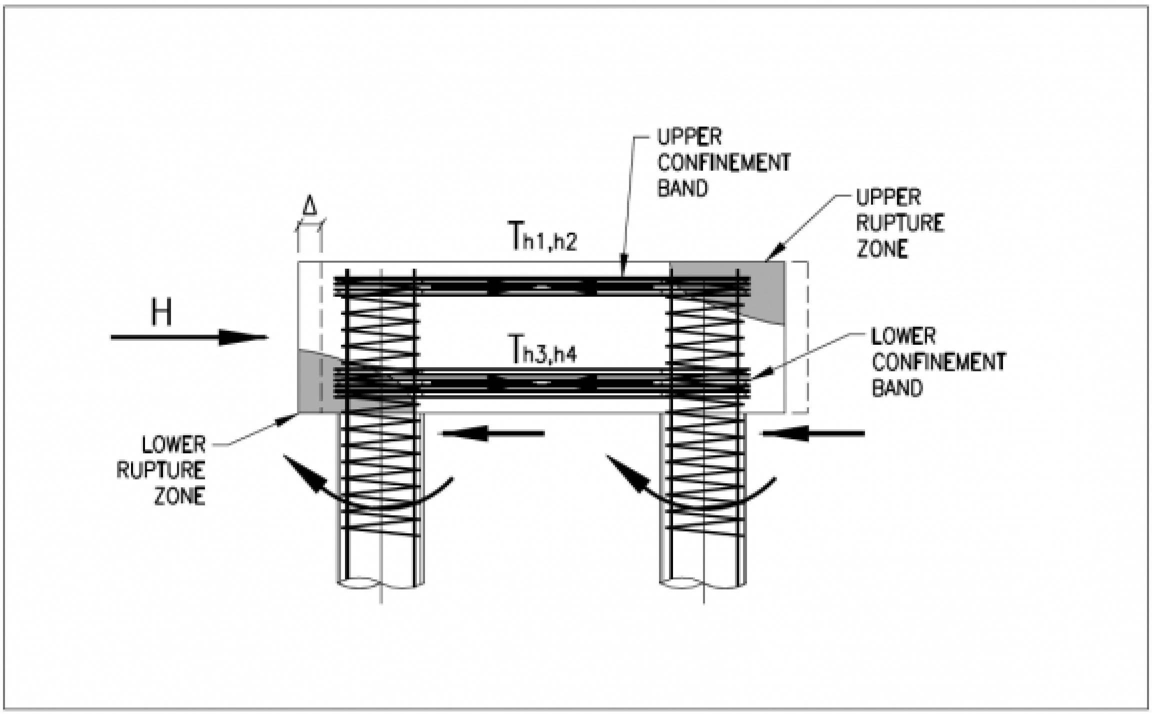

Figure 8:

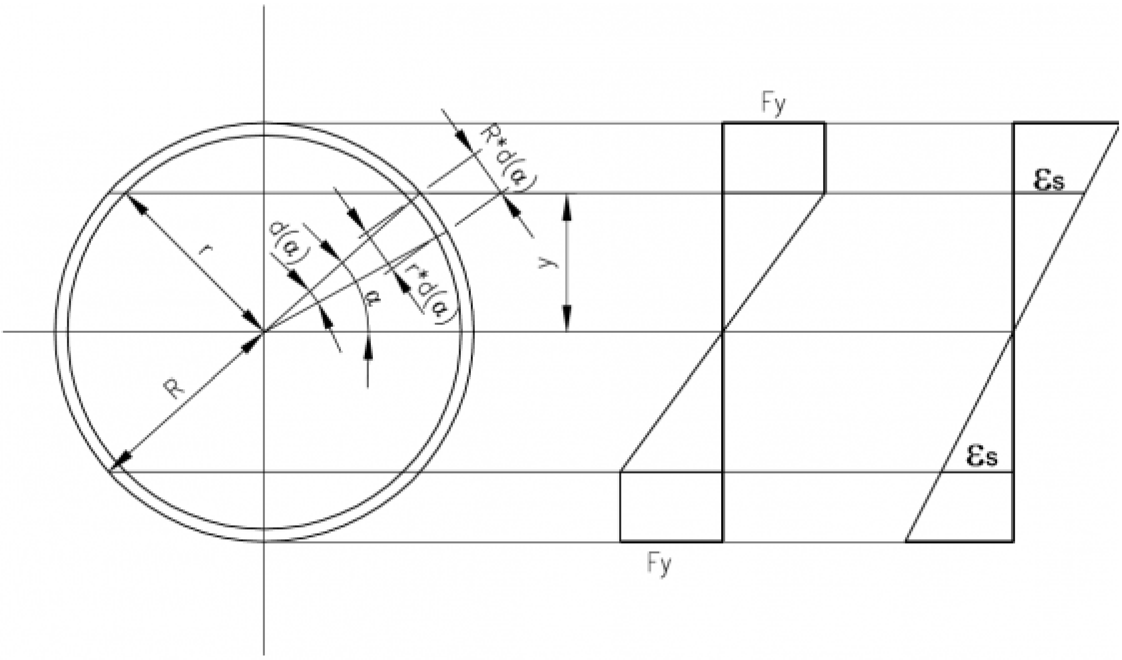

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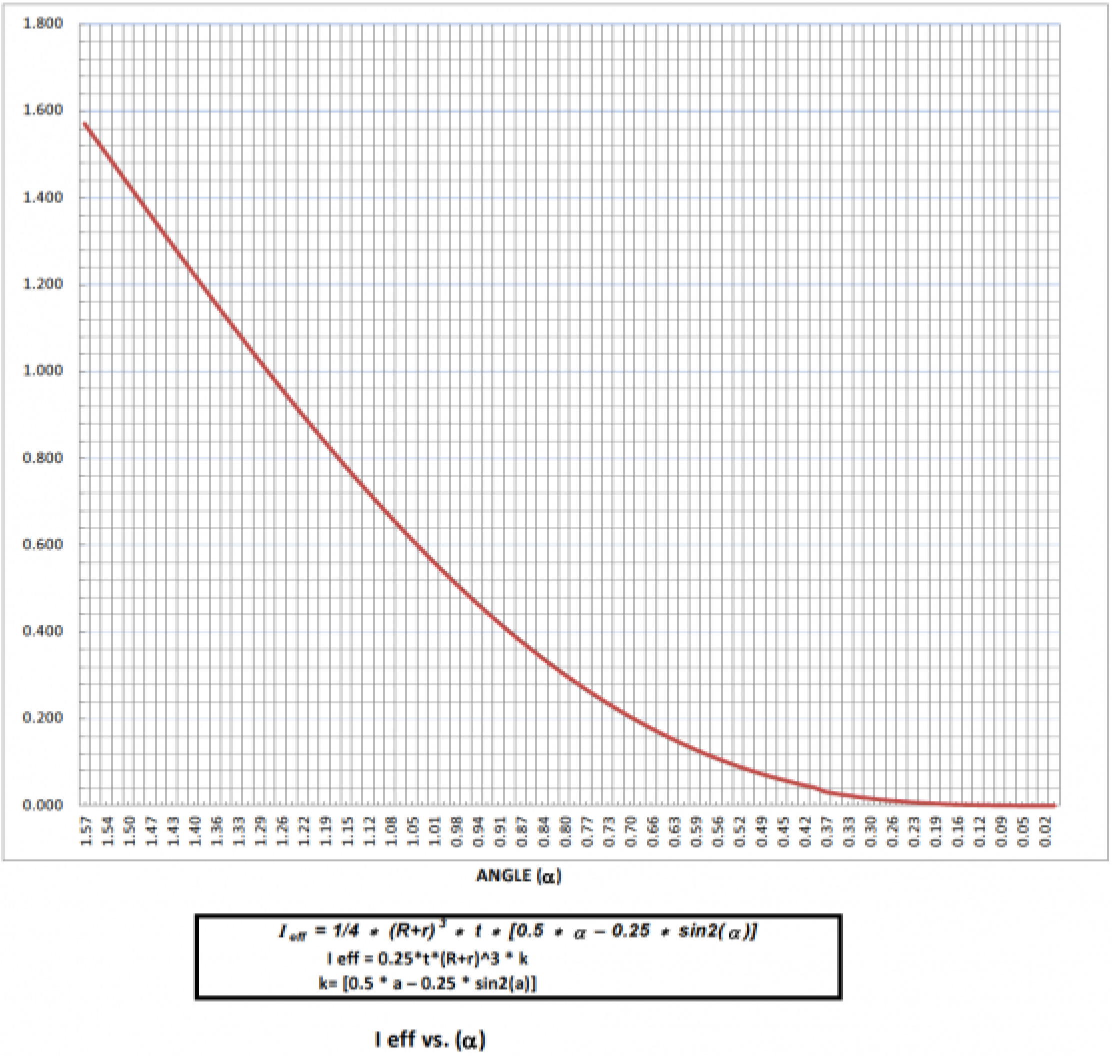
Figure 9: Figure 7 (



$I_{eff} = 1/4 * (R+r)^3 * t * [0.5 * \alpha - 0.25 * \sin2(\alpha)]$

I eff = 0.25*t*(R+r)^3 * k

k= [0.5 * a – 0.25 * sin2(a)]

I eff vs. (α)

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Figure 10: 2 and? 9 2015 E

2

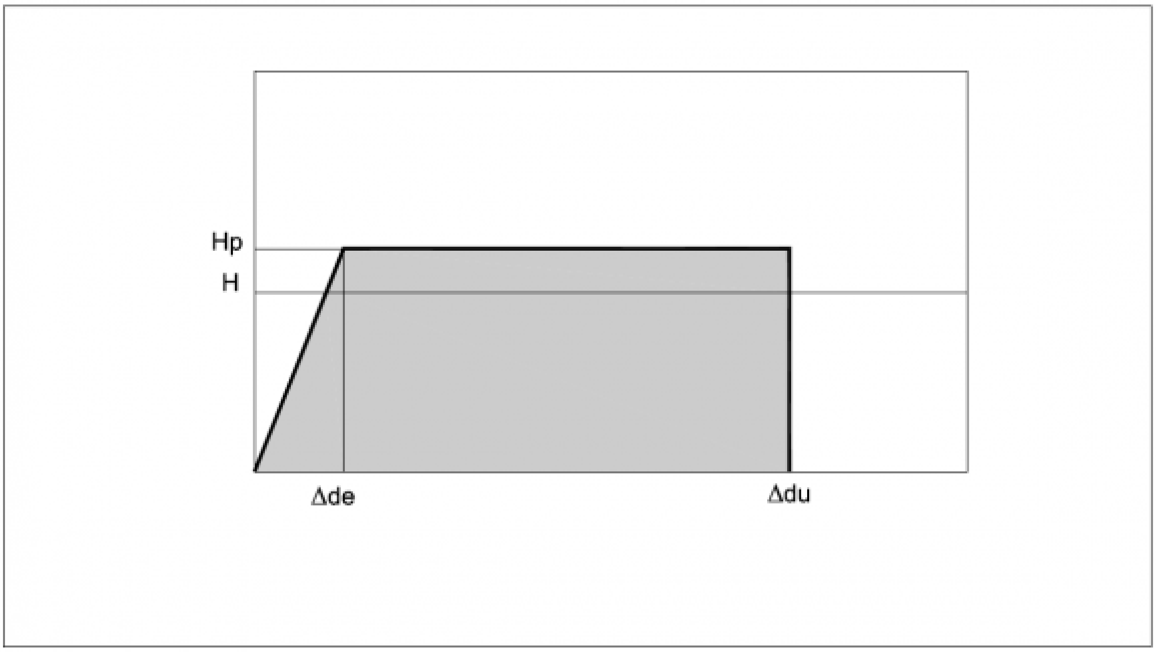
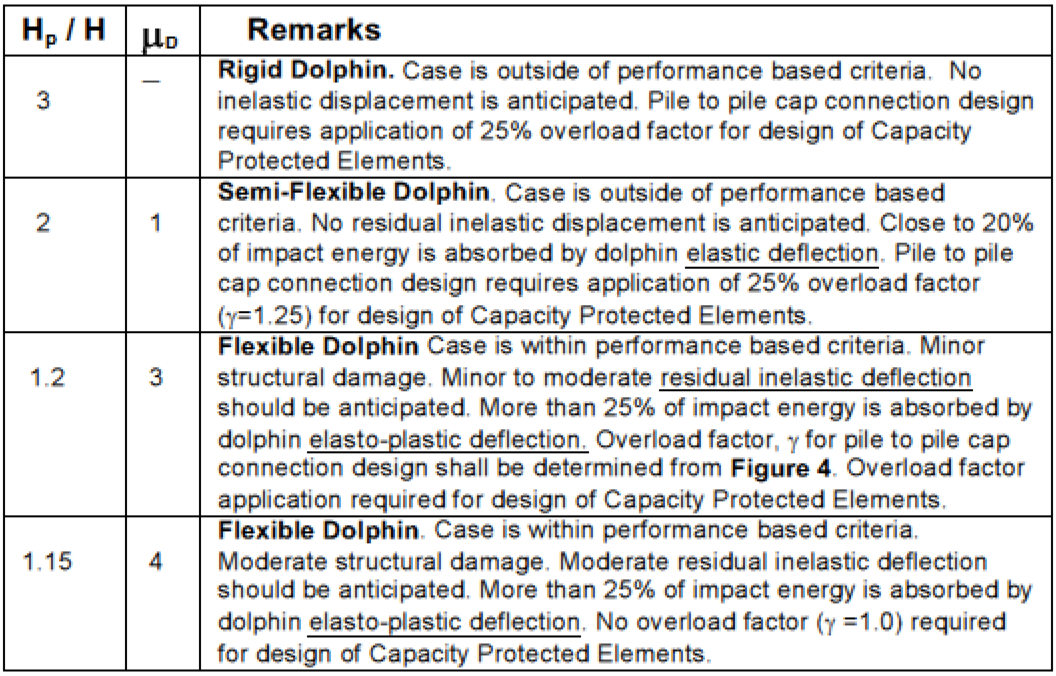


Figure 11: Figure 2 :



H_p / H	μ_D	Remarks
3	–	**Rigid Dolphin.** Case is outside of performance based criteria. No inelastic displacement is anticipated. Pile to pile cap connection design requires application of 25% overload factor for design of Capacity Protected Elements.
2	1	**Semi-Flexible Dolphin**. Case is outside of performance based criteria. No residual inelastic displacement is anticipated. Close to 20% of impact energy is absorbed by dolphin elastic deflection. Pile to pile cap connection design requires application of 25% overload factor (γ=1.25) for design of Capacity Protected Elements.
1.2	3	**Flexible Dolphin** Case is within performance based criteria. Minor structural damage. Minor to moderate residual inelastic deflection should be anticipated. More than 25% of impact energy is absorbed by dolphin elasto-plastic deflection. Overload factor, γ for pile to pile cap connection design shall be determined from **Figure 4**. Overload factor application required for design of Capacity Protected Elements.
1.15	4	**Flexible Dolphin**. Case is within performance based criteria. Moderate structural damage. Moderate residual inelastic deflection should be anticipated. More than 25% of impact energy is absorbed by dolphin elasto-plastic deflection. No overload factor (γ =1.0) required for design of Capacity Protected Elements.

Figure 12: Figure

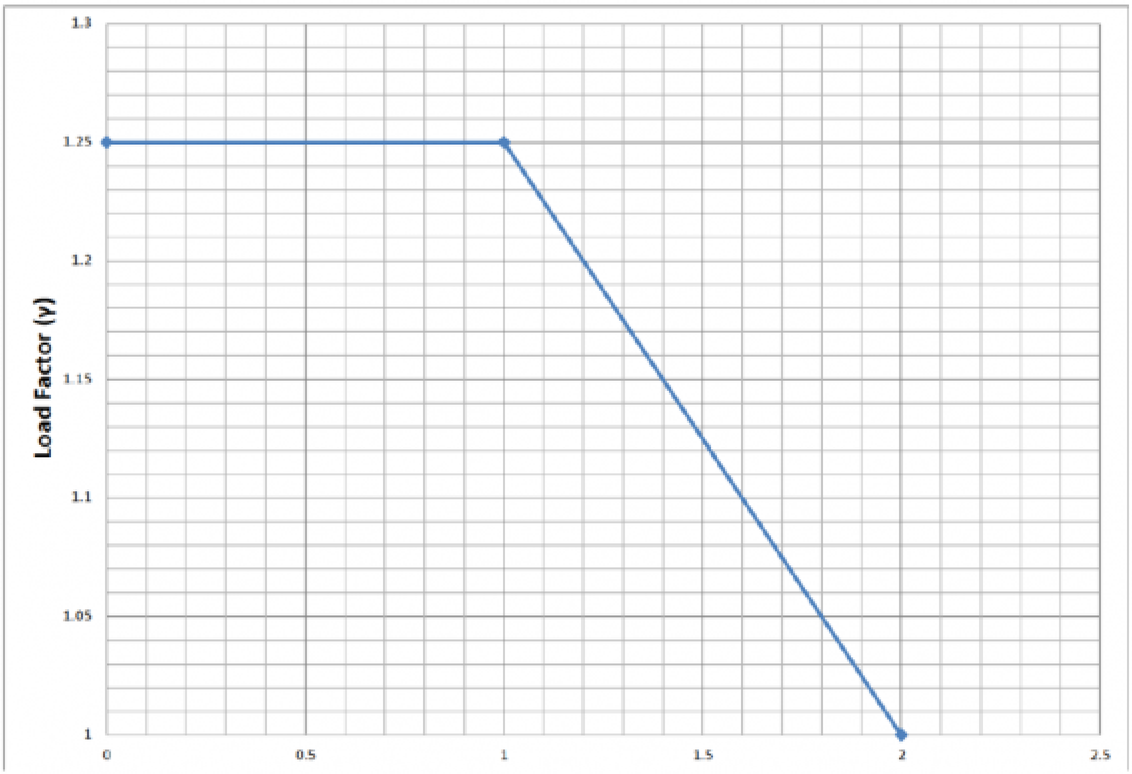


Figure 13:

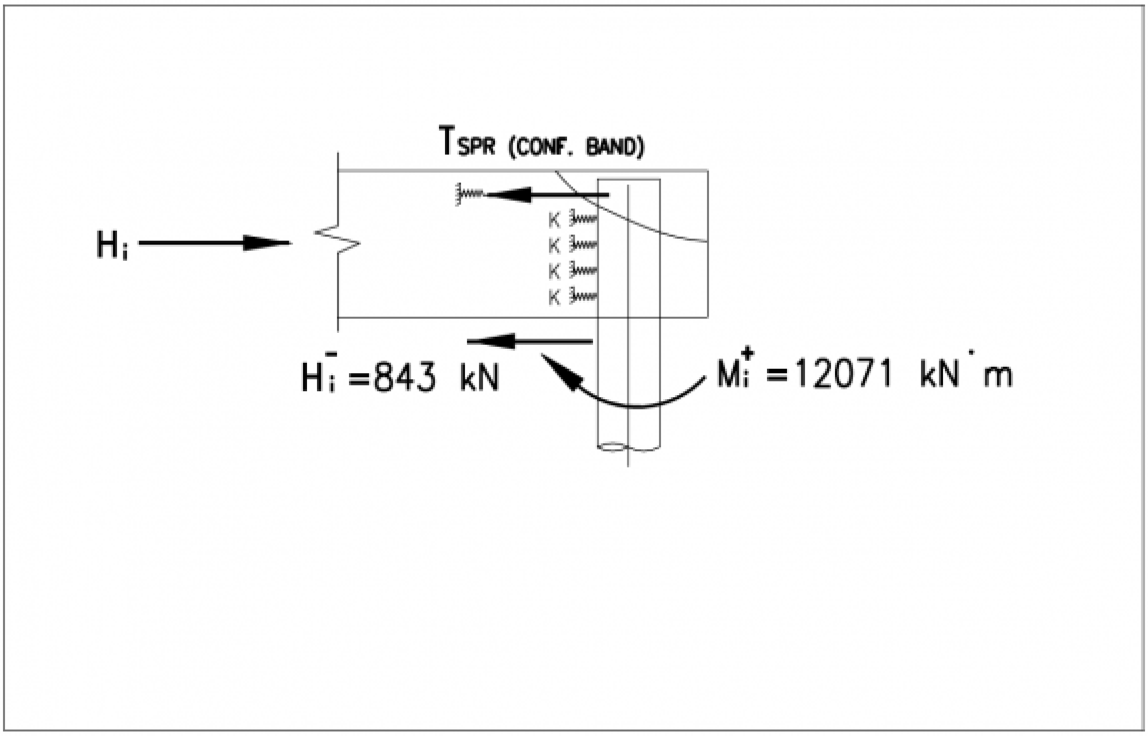


Figure 14:

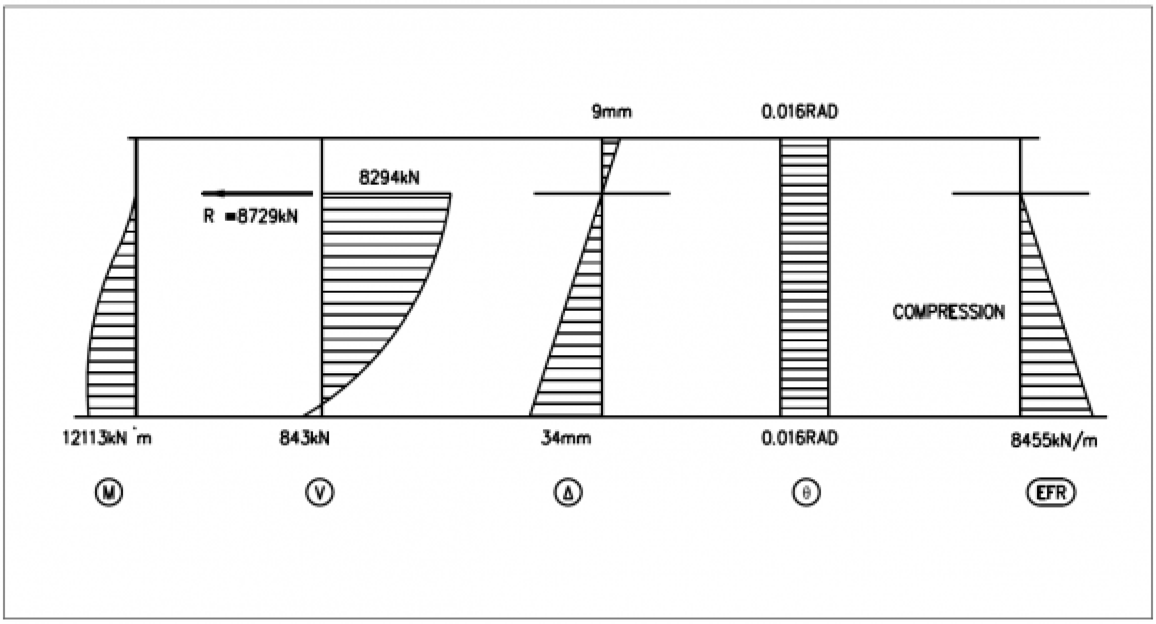


Figure 15: E

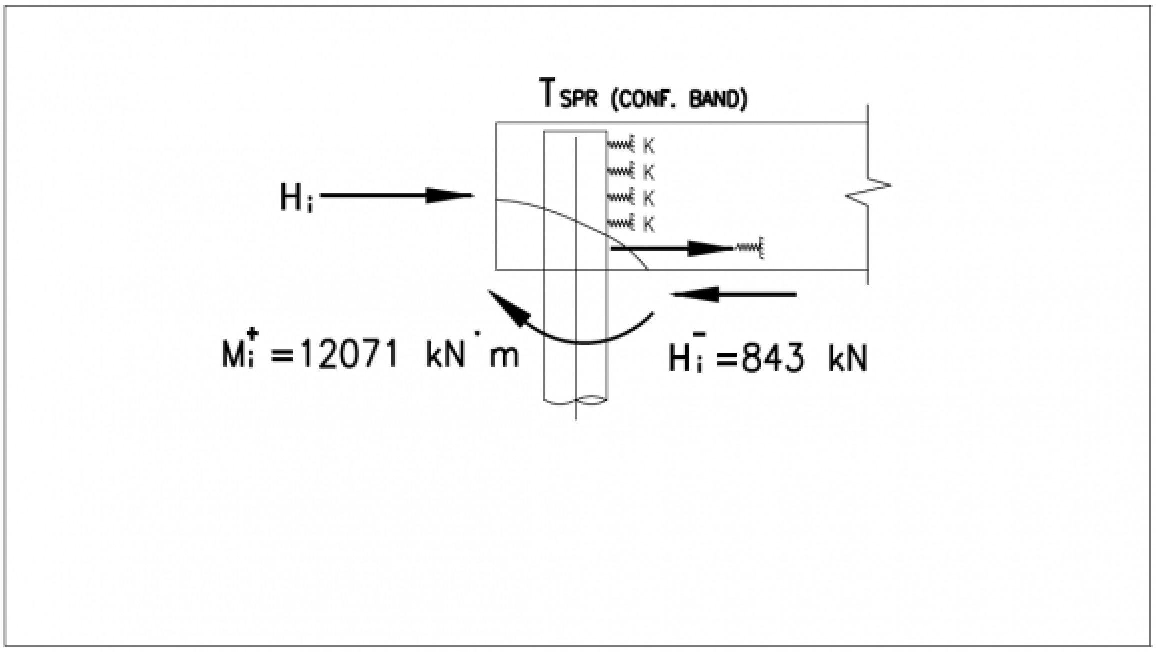


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Figure 16: Figure 4 :

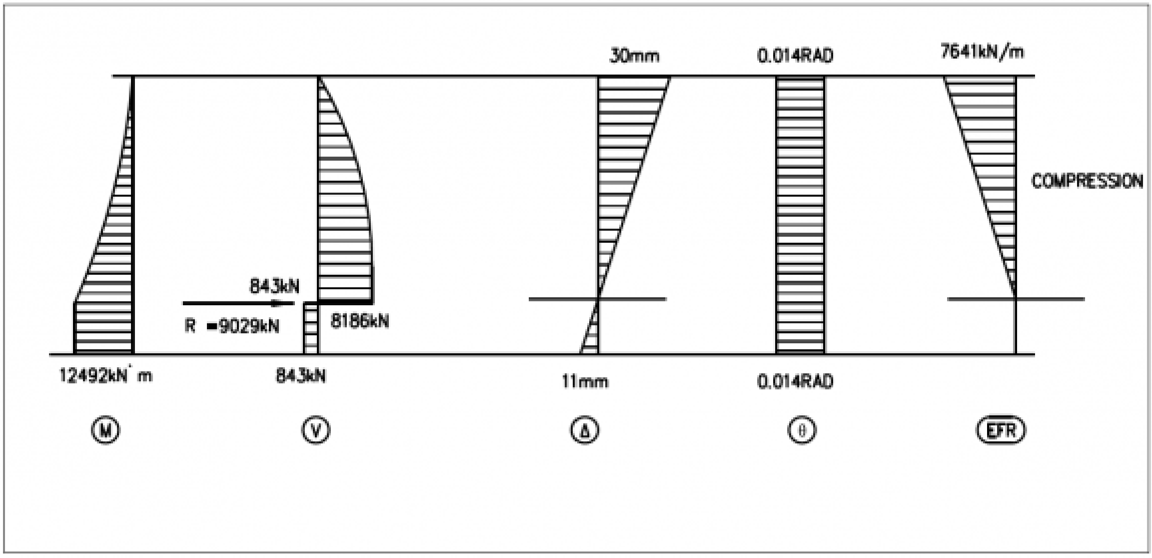

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Figure 17: Figure 5 a

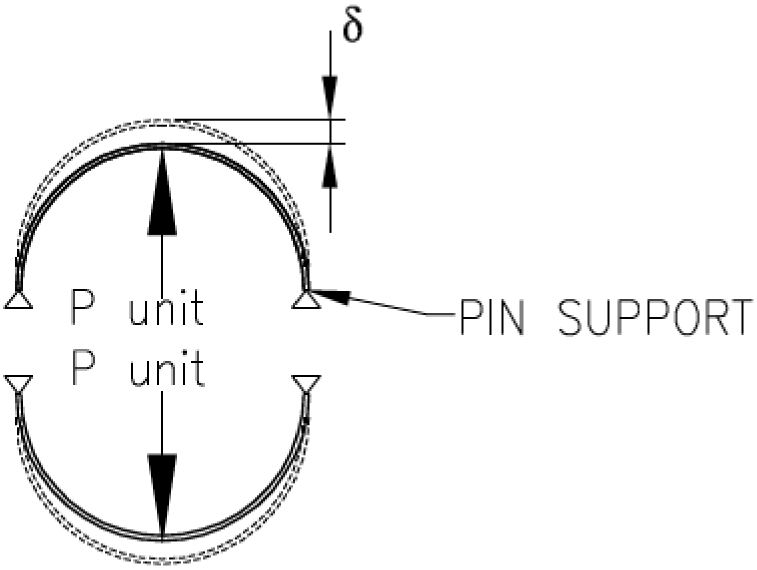

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Figure 18: Figure 6

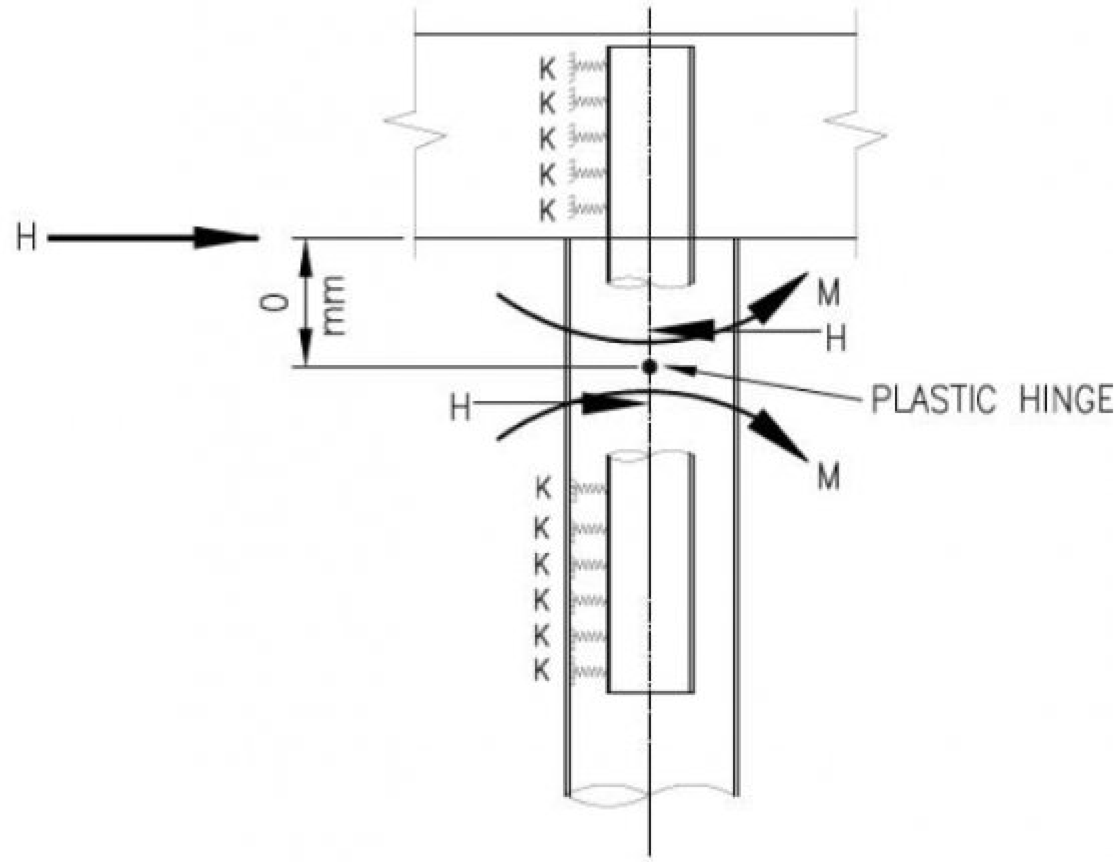

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Figure 19: Figure 6 :Year 2015 E

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.6, for example,
demands Load Factor =1.6 for Berthing loads, whilst
Australian Standard AS 4997-2005 requires
berthing Load Factor = 1.5. Effect of such variations is
negligent.
The more troublesome fact is that some
National codes make conflicting statements.
Australian national code AS 4997-2005 in cl.
5.3.2.5, for example, states that:
"The ultimate strength design of the fender
support structures should then consider the greater load
of:

[Note: ? Fender selection based on method 1 will satisfy energy absorption criteria of PIANC WG-33, but will not comply with load factors set for Berthing load by designated national standard.]

Figure 20: Table 3

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Global Journal of Researches in Engineering ( ) Volume XV Issue I Version E

[Note:). © 2015 Global Journals Inc. (US)]

Figure 21: Table 4

capability. Each dowel of the plug, in that case, acts as a single rebar, reducing rigidity of the shear plug to a sum of rigidities of individual dowels.

IV.

.1 Buckling and Ovalization

PIANC WG-33, cl. 6.6.4, purposely excludes possibility of plastic deformations in the soil due to the high unpredictability of such deformations and excludes two critical design parameters:

? local buckling and ? effect of ovalization on local buckling.

Buckling ovalization must be checked at abnormal impact force which is interpreted as an Ultimate Limit State force.

However, ovalization and local buckling frequently occur prior to plastic yielding. Corrosion, defined as a corrosion allowance, may and will greatly affect pipe pile ovalization and local buckling.

APA -RP2A 8 sets overall and local pile buckling criteria for large diameter pipe piles.

Pile Overload Analysis based on Plastic design (APA-RP2A, section 3.3.1c) provides the following equation:

Where, P u and M u are factored Axial force and Bending Moment. Z -plastic section modulus F xc <1.2F y -plastic local buckling depending on pile diameter to wall thickness ratio, D/t (API-RP2A, section 3.2.2.b) Considering average weighted load factor for Ultimate Strength design to be close to 1.5, the ratio of (1.2/1.5) *F y yields stress design limit of 0.8*F y .

PIANC WG-33 does not establish any credible criteria for large diameter pile buckling or pile ”egging,” while possibility of such failure prior to plastic buckling is high.

Section ovalization along the soil elastic foundation reduces pipe section moment of inertia, and simultaneously increases the chance of section buckling.

.2 Comments 13:

Whilst circular section can be checked for plastic deformations, there are no established or credible analytical procedures for the buckling of an oval section.

Therefore, it is important to exclude possible ovalization of the pipe pile below the ground surface. The ovalization problem presents designer with two options:

? Option 1: Adjust pipe shell thickness and verify that Von Mises stresses in the pipe shell below the

? Option 2: Fill pipe pile annular space with concrete. Ovalization of the section shall not be allowed, and Von Mises stresses shall be limited to 0.6*F y . Such a requirement is only slightly conservative, but fairly safe approach.

V.

.3 Model for Checking Pile Ovalization

This paper does not review ovalization problem below the ground level. Investigation of ovalization is a fairly complex task requiring soil spring / pipe shell interaction. Ovalization check below the ground level is generally required when D/t ratio exceeds 60, and is rarely presents a problem. Ovalization issue at the shear plug, however, is frequently neglected. On several reviewed projects the length of the shear plug embedment was underestimated, and at least on one project ovalization of the pile at the pile cap soffit was clearly visible. Model for checking ovalization at the shear plug is shown in Figures **??**2 and 13. The main reason for that check is to determine the required length of the shear plug embedment into the pipe pile. The length of the shear plug embedment shall be sufficient for prevention of the stresses in the pipe pile from reaching steel yield point. It would be recommended to keep stresses in the pile below 0.9F at Ultimate Limit State. Stress in the pile shall be checked assuming corrosion allowance at the end of the useful life of the structure.

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[Design of Piers and Wharves] *Design of Piers and Wharves*, UFC 4-152-01. (Unified Facility Criteria)

[Wg-33] *Guidelines for the Design of Fender Systems: 2002. International Navigation Association*, Pianc Wg-33 .

[Guidelines for the Design of Marine Structures] *Guidelines for the Design of Marine Structures*, (Australian Standard AS4997-2005)

[Rp-2a ()] *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms-Working Stress Design*, Api Rp-2a . 2007. American Petroleum Institute.

[Seismic Design Criteria. Version 1.6 (2010)] *Seismic Design Criteria. Version 1.6*, November 2010. CALTRAN ; California Department of Transportation

[Seismic Design of Pile -to-Pile Cap Connections in Flexible Pier Structures. Vitaly B. Feygin. Structure, SEI (2012)] *Seismic Design of Pile -to-Pile Cap Connections in Flexible Pier Structures. Vitaly B. Feygin. Structure, SEI*, March 2012.

[Port and Beach (2013)] *Wharf Design Criteria. POLB WDC Version 3.0*, Long Port , Beach . February 29, 2013.