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Finite element local analysis of wave slamming on offshore structure

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ABSTRACT

Offshore platforms are exposed to waves slamming event. Waves hitting the columns with a high velocity are in many cases the design criteria for column structure. This paper focuses on the analysis of wave slamming on floating platform column. Significant for wave slamming pressure is load history, which is usually based on model test. Wave slamming loads were defined on all four walls of column to assess the worst place. For south wall of column three positions exposed to slamming loads between elevation 21.000 (SWL) and elevation 35.500 were checked. Dynamic analysis has been performed with nonlinear FEM program ABAQUS /explicit. The steel was modeled as an elastic-plastic material with isotropic hardening.

Key words: explicit analysis, FEM, offshore structures, wave slamming

INTRODUCTION

Wave forces on offshore structures have very often been analyzed especially for slender cylinder and walls. For non – breaking waves on vertical cylinders those forces are described by well known Morrison equation [1]. Morrison equations are widely used in engineering practice although can not be used for all wave conditions.

Forces responsible for breaking waves, (especially plunging waves) can be more than two times higher than those of non-breaking waves of comparable size [2]. Duration of these impact forces (also called slamming) is extremely short. Many laboratory and experimental studies [3] for regular and non regular waves describe intensity, peak pressure, time history and distribution on cylindrical surface of piles. Theoretical description of impact (forces) was first developed by von Karman [4] .

According to these theories the maximum line forces on vertical piles can be given by following equation:

$$f_i = C_s \cdot \rho \cdot R \cdot v^2 \tag{1}$$

where:

C_s – slamming coefficient, is equal π (due to von Karman theory) or 2π (according to Wagner),
ρ – mass density of fluid,
R – radius of the cylinder,
ν – velocity of the mass of water.

Time history of impact loads was usually calculated according to Goda [5]. The new approach to description of load time of impact forces was developed by Wienke [6]. Numerical simulation of slamming based on CFD and comparison with results obtained from [6] can be found in [7].

Complexity of real wave breaking and different types of plunging breakers (i.e. early, perfect breaking) maximum forces calculated according to theories and measured in experiments are well described in [8].

Due to this complexity maximum impact pressure on walls (as on cylindrical structures) forces calculated according to Karman theory (water - hammer analysis) are 8-10 times greater than the measurements. Also, other theoretical attempts for prediction of maximum impact pressure give unreasonable results [8].

The safe and economic design of offshore structures such as (floating platforms) depends significantly on the designed wave loads. In DNV recommended practice [9] prediction of wave impact on plates is based on water-hammer analysis models but experiments are also recommended, in order to give correct estimates of impact loads.

Space averaged slamming pressure over broader area should be calculated from formula:

$$p_s = \frac{1}{2} \rho C_{Pa} v^2 \tag{2}$$

Slamming coefficient for flat panels should not be taken as less than C_{Pa} equal 2π. There is not given any other information about loading time history, area, etc. According to formula (2) calculated value of averaged pressure can be very high. For ultimate load state (ULS) local plastic deformation of structure should be considered.

WAVE SLAMMING ON COLUMN

Analysed platform has almost identical columns. Wave slamming analysis is based on one of columns. The column is located at the south / west side of the platform hull. Platform north coincides with geographical north for all analysis purposes (i.e wave slamming directions). The column structure itself shows lack of symmetry. Wave slamming can occur on one of four walls. Loads on the inner column walls were reduced by 20% due to shielding effect from the other columns.

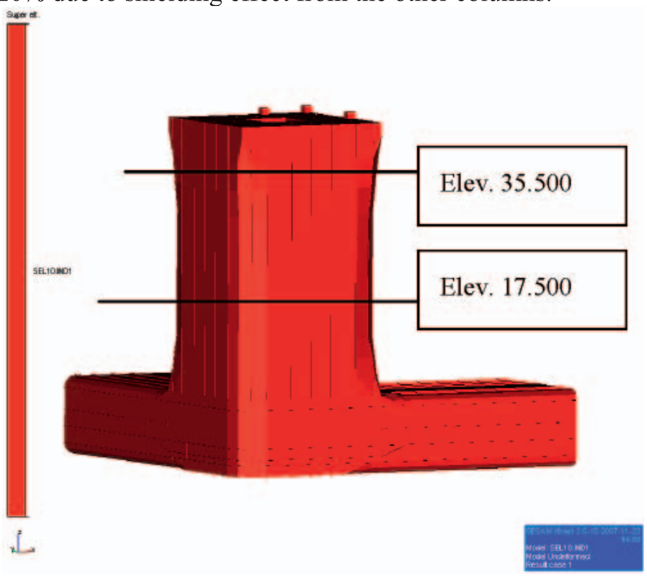

Fig. 1. Model of the analyzed sector of the column

Analysis methodology / design criteria

This section describes the methodology used to verify the structural strength of column exposed to breaking waves based on waves taken from Metocean [10]. Load time history (Fig. 2) is derived from model tests and applied in dynamic analysis with non-linear FEM program ABAQUS. The slamming event has a duration of 160 ms with a peak value at 30 ms. After the peak value the pressure decreases to 10% of the maximum value. This load history is very similar to the one shown in [8]. In the analysis, it is assumed that the main load is the wave breaking pressure and platform has no initial speed.

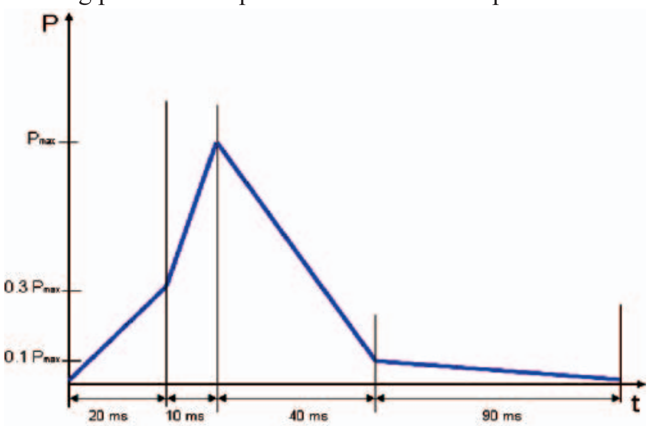

Fig. 2. A design load history for slamming loads on the column face.

The formula for calculating the pressure is shown below:

$$p = LF \cdot \frac{1}{2} \cdot \rho \cdot C_s \cdot v^2 \qquad (3)$$

Slamming coefficient Cs is equal to 2π and load factor LF is assumed as 1.30.

Used slamming coefficient, load factor, wave velocity and pressure are calculated according to DNV recommended practice [9]. Due to the mix of air and to the water density ρ is equal to 0.9 t/m^3.

Tab. 1. Wave slamming pressure parameters

Slamming load on panel (according to DNV CN 30.5)								
Wave from direction	100 year RP Hs	Wave height Hb = 1.4 x Hs	Elevation for top of wave crest	Crest above SWL	Height of window	Velocity [m/s]	Pressure [MPa]	Line load [N/mm]
North 0°	13.1	18.3	31.2	10.2	4.6	14.2	0.736	460
East 90°	3.1	4.3	24.4	3.4	1.1	6.9	0.174	109
South 180°	14.9	20.9	32.8	11.8	5.2	15.1	0.837	523
West 270°	12.2	17.1	30.5	9.5	4.3	13.7	0.686	428

Slamming can only affect areas above still water level (SWL), SWL is at elevation of 21 metres.

Exposed area could be anywhere between still water line (el. 21 m) and the top of wave crest. Different positions are analysed for south wall of column c1 where calculated wave slamming pressure was the highest. Areas used to apply wave slamming pressure are shown on Fig.3. Width, height, and wave slamming pressure value for each area can be seen in Tab. 2. Horizontal width: the flat surface between bilges, but limited to a width of about 8 meters corresponding to a sector of 45° (with origin in the centre of the column). Vertical height: one fourth of the wave height (given in Tab. 2).

Tab. 2. Areas exposed to wave slamming pressure on south wall of column

Flat plate pressure distribution area south wall of c1:	A1	A2	A3
Top of exposed area	**el. 32250**	**el. 29250**	**el. 26250**
Width [m]	8.125	8.125	8.125
Height [m]	5.5	5.5	5.5
Peak Pressure [MPa]	0.837	0.837	0.837

Design criteria were defined as follows: stiffeners / web frames should have ultimate strength to sustain slamming pressure from breaking wave with a return period of 100 year including a load factor of 1.3, It must be ensured that

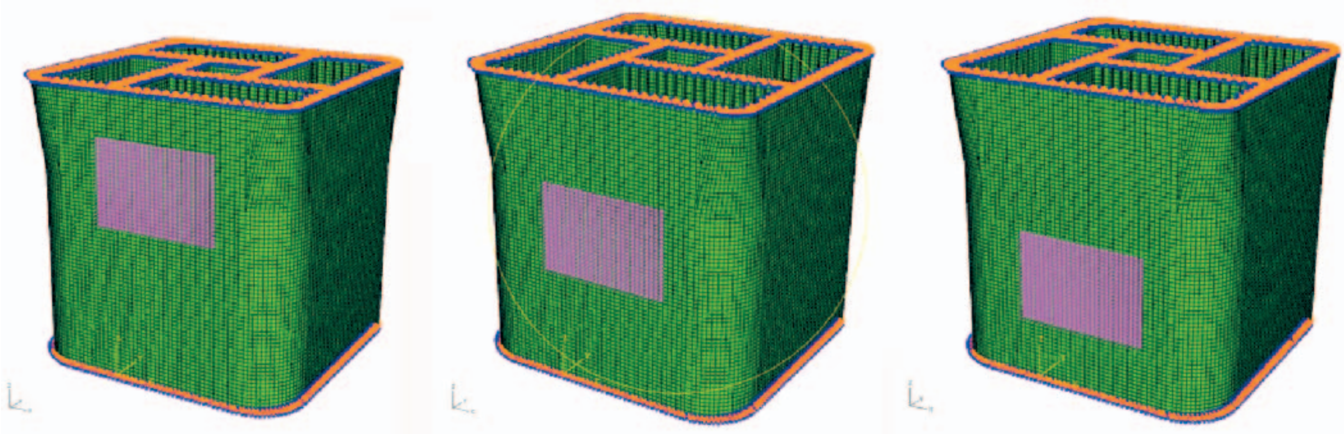

***Fig. 3.** Column c1 south wall. Wave slamming pressure exposed area A1 -A3*

the structure hit by the breaking wave will stabilize in a load history, non-linear analysis using plastic strain formulation (acc. to NORSOK N-004 [11]).

DYNAMIC FEM ANALYSIS

Explicit solution method

Abaqus V6.7 explicit was used for the calculations. The explicit method is very well suited for the analysis of high speed dynamic events and complex and highly non-linear problems [12].

Explicit calculations are conditionally stable and the maximum time increment is limited by the element size and the element mass. Automatic time incrementation was used and time increment was about 7.75E-06 s. Total time of explicit dynamic analysis in ABAQUS was set to 0 - 1.1 [s] and it is much longer than the duration of slamming loads (0 - 0.16 [s]). The averaged slamming pressure was applied to the structure, load history was defined by using amplitude options. Amplitude is varying between 0.0 and 1.0, (see Fig. 2). Mass proportional damping value was defined as 0.02. For improving numerical solution artificial damping is also included in explicit calculation procedures by default. Upon wave impact, kinetic energy of wave slamming is absorbed by elastic-plastic deformation of column structure.

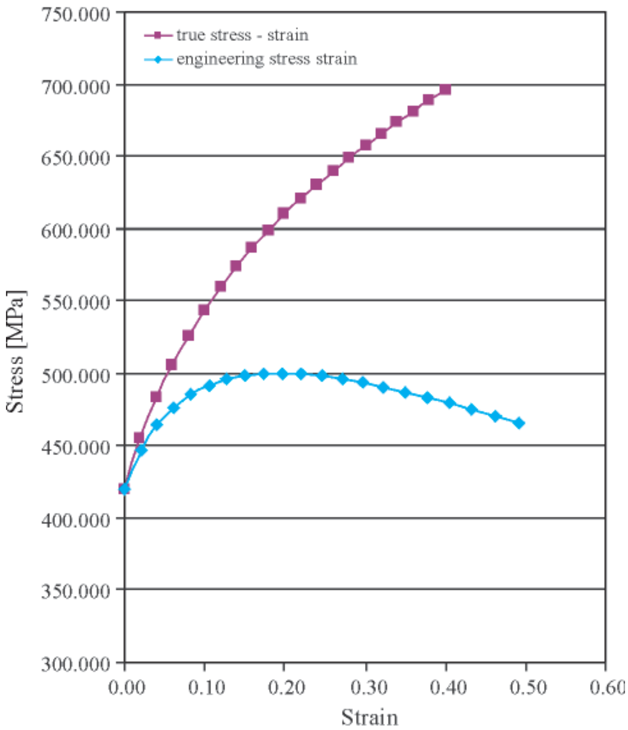

***Fig. 4.** Hardening behavior of 420 MPa steel*

Material model

All plates and stringers in the column are made of 420 MPa steel. In the calculations, the yield stress of the material was taken as 420 MPa. An isotropic hardening model was defined in ABAQUS.

The hardening behavior (engineering as well as true stress-strain) of the material is explained in Fig. 3. In a tensile test, the force and the elongation are measured. True stress is the force per unit of deformed cross section, engineering (nominal) stress is the force per unit of the initial cross section. True strain is based on the deformed length, whereas engineering strain is the elongation divided by the original length. An engineering strain of 20% is the same as a true (logarithmic) strain level of 18%.

Geometry and FEM mesh

The relevant part of the column for the slamming analysis is between the elevation of 17.5 m and 35.5 m. Below deck at elevation of 26.5 m, each side of the external shell is supported by 2 bulkheads. Over this deck, the shell is supported by one bulkhead and one cross-over I-beam from the central void. Only the upper part is considered, since the horizontal framing is much weaker than below the deck. The outer skin and the bulkhead walls are reinforced by stringers HP 320x12 that are equally spaced at 0.625 m. In horizontal planes, the outer skin

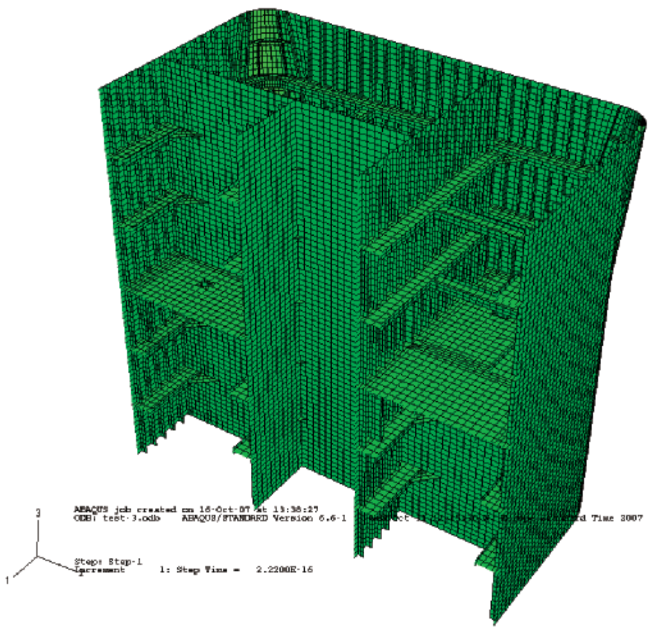

***Fig. 5.** Cross sectional view of the column*

and the bulkhead walls are supported by frames, which are equally spaced at 3.0 m. An I-beam connects the corner of the central void with the outer skin.

The FEM model was made with a grid of nodes that were spaced in horizontal direction of 312.5 mm and 250 mm in vertical direction and the mesh is almost square. In the FEM model, the frame flanges were therefore modeled as 300 mm high and 20 mm thick. Stiffener web was assumed as 300 mm long and 12 mm thick. For the stiffeners on south wall the bulb was modeled with T3D2 elements .

With the given mesh size, there are 5 elements over the web of the frames and their behavior will be described quite accurately. The stringers have two elements in their web, and their behavior is less accurate, but still sufficient. Square shell elements of type S4 were used everywhere, except for the brackets where some triangular shell elements of type S3R were used as well. The brackets between bulkhead and frames were modeled as triangles whose short sides are about 1600 mm long. The I-beams were modeled with shell elements of type S4.

Eight millimeters corrosion allowance was used for column skin plates (up to 5 meters above SWL) and used shell thickness = 16 mm. Thickness of bulkhead and deck was 12 mm.

Load cases

A wave slamming load is a local load. Waves hit only selected (relative small) area of column outer surface. Although wave breaking pressures act only local, deformation and stress level can be very serious. We can compare this results to results obtained from global analysis. Displacements from global model (SESAM) have been applied as prescribed displacements in the corresponding nodes of the column local model (ABAQUS). ABAQUS model used in wave slamming analysis was more detailed than the model used in the global analysis. Load cases for wave slamming on all four walls correspond to loads described in Tab. 1. Load cases on south wall correspond to Tab. 2. Gravity was included and gravity constant equal to 9.81 m/s^2.

FEM RESULTS

Global and slamming loads

Analysis show that stress level from global model loads is very small especially if we compare it to the results from wave slamming analysis. Von Misses stress distribution on east and north wall of column can be seen on Fig. 6.

Values of wave breaking pressure acting on south, west, and north walls are considerable. Von Misses's stresses level exceeded yield limit of 420 steel. On east wall von Misses's stresses level didn't exceed yield limit and structure of east wall deforms only elastic. For south, west and north walls the highest plastic equivalent strains (PEEQ) occurred in the web of frame (Fig. 7). The highest strain level was 2.8 % on south wall in the web of the frame. Plastic equivalent strains for other walls and other parts of column are shown in Tab. 3.

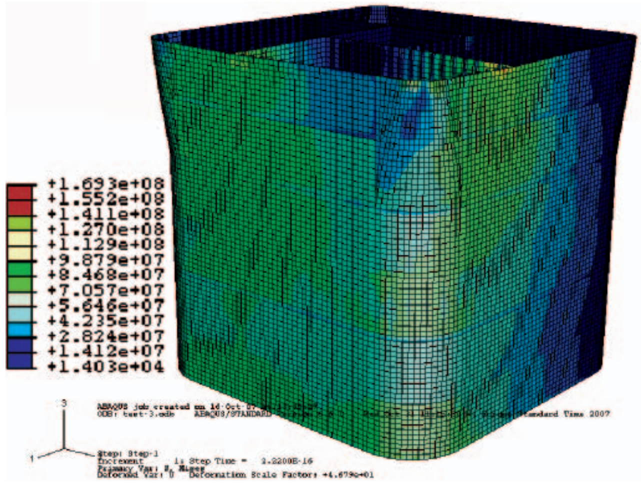

Fig. 6. *Von Misses stress distribution from global model load [Pa]*

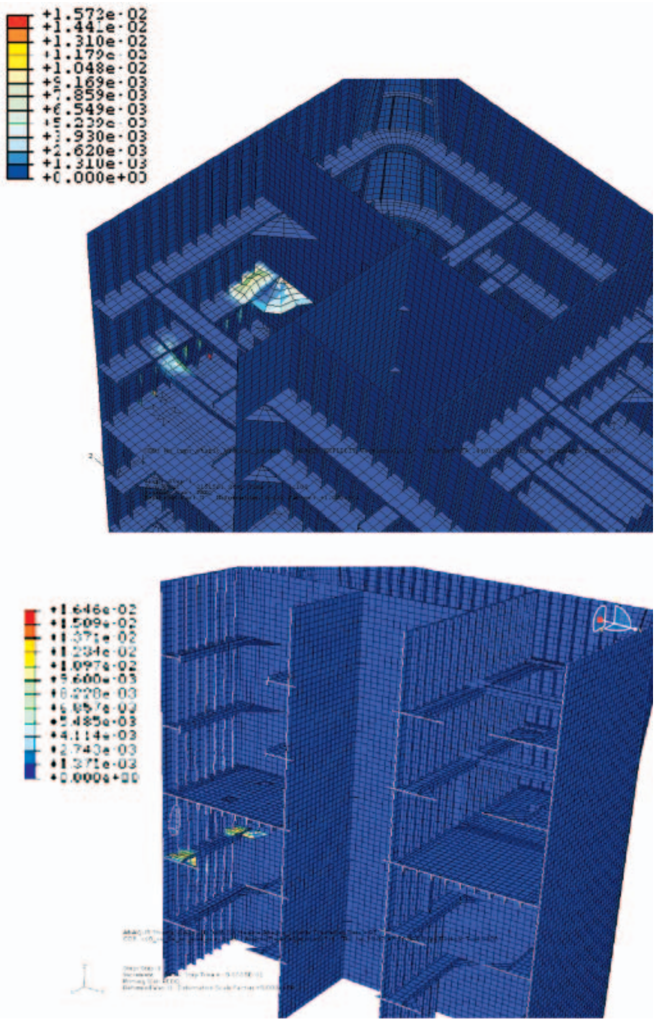

Fig.7. *PEEQ strains on south wall of column*

Tab. 3. *Maximum plastic equivalent strains PEEQ in columns parts*

Maximum equivalent plastic strain (%)							
	slamming pressure			frame		stiffener	
Load case	**(MPa)**	**skin**	**bracket /frame bulkhead/**	**web**	**flanges**	**midspan**	**end**
south wall	0.837	-	1.4	2.8	0.6	1.9	0.4
west wall	0.686	-	0.5	-	-	1.4	1.1
north wall	0.736	-	1.3	1.1	0.3	0.9	1.5
east wall	0.174	N/A	N/A	N/A	N/A	N/A	N/A

Plastic strains as a function of time

It is important to check whether plastic strains level reminds constant after first occurrence. It is possible when dynamic/explicit analysis time is much longer then duration of slamming pressure load. Analysis time was set from 0.0 to 1.1 s. Local plastic strains were checked for different exposed areas (acc to Tab. 2) on the south wall.

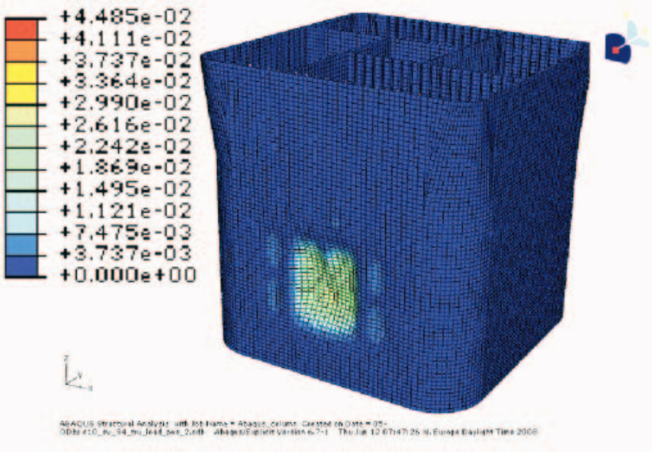

Fig. 8. South wall – exposed area A3, Displacement [m] at Time =50 ms.

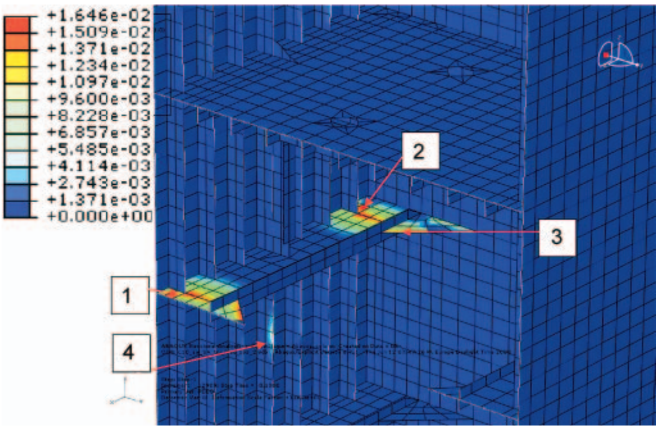

Fig. 9. South wall – exposed area A3, Time =50 ms, PEEQ strains level

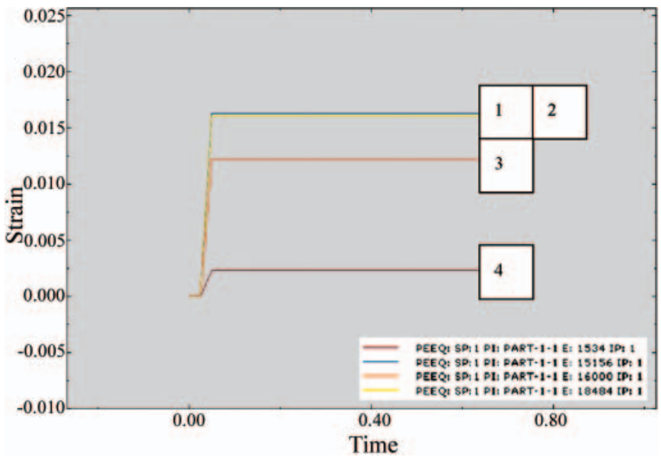

Fig. 10. South wall – exposed area A3. Local plastic equivalent strains (PEEQ) at selected elements as function of time.

CONCLUSION

The results shown herein presents the dynamic nonlinear elasto-plastic analysis of structure of floating platform. Slamming pressures calculated according to DNV recommended practice for ultimate load state (ULS) may compound the difficulties in adequately design. Stresses from global analysis are very small especially if compare to wave slamming results. In the column structure loaded with the 100 year wave slamming loading (used load factor 1.3) local yielding occurred. Maximum plastic equivalent strains (PEEQ) level was about 2.8%, found at time equal to 30 [ms] (maximum of load amplitude). During rest of analysis time (30 to 110 [ms]) PEEQ strains level remained constant. Local plastic deformation of structure should be acceptable. The numerical results satisfy equilibrium and symmetry (Fig. 7). Further investigation of other aspects of analysis i.e: local mesh refinement, possible imperfection and local buckling of stiffeners can be also quickly performed with ABAQUS system.

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