Structural Integrity Study for Additional Piles on an Existing Jacket Structure in Western Indian Offshore

Praveen Bhat and Bakul Master

Abstract Oil and Natural Gas Corporation (ONGC) operates more than 265 steel jacket-supported platforms installed in water depths ranging from 25 to 90 mts. and secured to the seabed using steel piles. Quite large number of platforms have either exceeded their design lives and/or undergone modifications/mitigation/strengthening due to change in design premises and/or revamping projects executed for enhanced oil recovery. This calls for requalification studies for their extended "fit for use purpose." This paper describes the structural integrity assessment of an existing platform found to have highly overstressed piles and failing members and joints based on design-level analysis. A pushover analysis has been carried out to assess the reserve strength ratio (RSR) for checking the structural adequacy of the jacket structure, and suitable mitigation measures have been suggested for the particular platform as a combination of additional retrofit members/piles, removal of redundant facilities, and strengthening of members/joints, etc.

Keywords Jacket structure · Design in-place analysis · Ultimate strength analysis RSR

1 Introduction

The hunt for Black Gold started in the Indian offshore region when Oil and Natural Gas Corporation Limited (ONGC) started its operations in the western offshore region of India in the year 1976. Since then, more than 265 well, process, and living quarter platforms have been installed and operated by ONGC. By now, quite a large number of platforms have either exceeded their design lives or undergone/undergoing modification/mitigation measures due to change in design premises and/or revamping projects executed for enhanced oil recovery. Re-assessment of

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R. Prakash et al. (eds.), *Advances in Structural Integrity*,
https://doi.org/10.1007/978-981-10-7197-3_32

these offshore platforms involves structural integrity check after taking due consideration of change in design premises along with new loads and structural damages, if any.

This paper describes the summary of the work carried out at the Institute of Engineering and Ocean Technology (IEOT), ONGC, on the project of global static in-place structural integrity check of an existing platform and consequential mitigation measures. The mitigation measures suggested for the particular platform are in combination with the removal of redundant equipment and appurtenances, restriction on marine growth, strengthening of members/joints, and additional retrofit members/piles. The paper highlights the main findings of the study with special emphasis on the jacket and pile structure.

2 Structural Analysis

2.1 Design-Level Analysis

The study for this typical jacket structure, located in western offshore, for the structural integrity check on specific requirements from the asset/platform operator in the context of its design life has been outlived. The salient features of the platform have been listed in Table 1 and Fig. 1.

An initial global static in-place design level analysis of the platform has been carried out for 100-year extreme storm condition with 85% environmental loading considering all lateral loads, i.e., Wave, Current, and Wind, with a load factor 0.85 (reduced environmental criteria1) in combination with other design loads including gravity loads due to self-weight and production facilities installed on the platform topside. A marine growth thickness of 100 mm from EL (+) 6 m to EL (−) 30 m and 50 mm from EL (−) 30 m to mud line has been considered in the analysis.

The primary structural members have been checked for yield, stability, and nominal joint strength assessment for 100-year extreme storm condition [1]. In the

Table 1 Platform details

Water depth	77.455 m
No. of main piles	4
No. of skirt piles	2
Diameter of main piles	1.372 m
Diameter of skirt piles	1.372 m
Piles vertical penetration for main piles	95.555 m
Piles vertical penetration for skirt piles	77.724 m
Production details	
No. of conductors	12 (9 inside + 3 clamp on)
No. of risers	6 (1 * 4″ + 2 * 6″ + 1 * 10″ + 1 * 12″ + 1 * 14″)

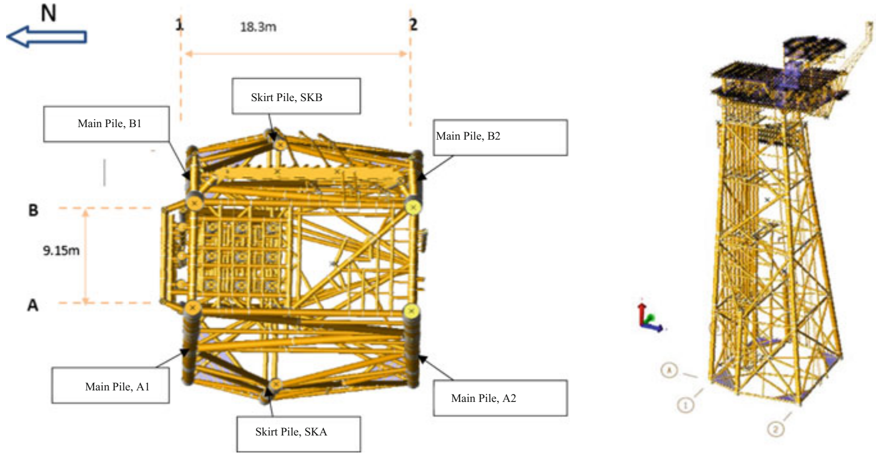

Fig. 1 Key plan and 3-D view of the jacket structure

design-level analysis, all the piles have been checked for axial load carrying capacity and the pile head stresses.

The results of the design-level analysis revealed that for 100-year extreme storm condition with 85% environmental loading and associated design loads, the factor of safety (FOS) against axial capacity for all the piles is more than 1.50 under various load cases in both compression and pull out. In pile head stress utility ratio check, all the piles were found to have material utilization higher than the maximum permissible limit of 1.0. Hence, re-analysis was performed after incorporating load reduction measures. The load reduction measures comprised of removal of redundant sump and pump caisson, non-consideration of future riser protector, and restriction of marine growth thickness to 50 mm throughout. The results of the re-analysis showed that still some of the piles were highly overstressed with a UC value higher than the permissible limit of 1.00 (refer Table 2).

Member strength assessment revealed that six structural members were having capacity utilization more than the API (RP-2A-WSD) specified limit value of 1.0 with a maximum capacity overutilization by 24%. In joint strength check, three structural joints were showing high capacity utilization with UC ratios exceeding the acceptable limit of UC ratio of 1.0 with a maximum capacity overutilization by 28%.

2.2 *Simplified (Linear) Ultimate Strength Analysis*

Subsequently, simplified (linear) ultimate strength in-place analysis with 100% environmental loading was performed, and few primary structural members and joints were found to be having utility ratio higher than the acceptable value of 1.2781. Hence, few structural members and joints were not passing the assessment

Table 2 Pile FOS and pile UC values for original condition (with 85% environmental loading) with suggested load reduction measures

Pile No.	Location	Axial force in comp. (MN)	Pile capacity in comp. (MN)	Min. FOS in compression	Axial force in pull out (MN)	Pile capacity in pullout (MN)	Min. FOS in pull out	Max. pile UC
1	A1	14.334	38.781	2.71	10.225	30.020	2.94	0.948
2	B1	17.057	38.781	2.27	8.984	30.020	3.34	1.006
3	A2	19.475	38.781	1.99	13.539	30.029	2.22	1.300
4	B2	20.452	38.781	1.90	12.521	30.029	2.40	1.382
5	SKA	10.695	23.152	2.16	4.268	23.759	5.57	0.945
6	SKB	13.189	23.152	1.76	3.544	23.759	6.70	1.063

requirement even as per the simplified ultimate strength analysis check (Linear global analyses check as per API-RP-2A (WSD)).

Member Check Results:

S. No.	Member	UC ratio[a]	UC ratio[b]
1	203L-0743	1.034	1.278
2	201L-0004	1.099	1.352
3	202L-0005	1.043	1.255
4	203L-0006	1.243	1.530
5	204L-0007	1.119	1.347
6	0001-404L	1.008	1.181

Joint Check Results:

S. No.	Brace member	Location	UC ratio[a]	UC ratio[b]
1	0007	Row-A, X-brace joint, b/w EL (−) 52.76 m and EL (−) 77.455 m	1.280	1.538
2	0253	Horizontal level, EL (−) 52.760 m	1.232	1.426
3	0005	Row-B, X-brace joint, b/w EL (−) 52.76 m and EL (−) 77.455 m	1.225	1.466

Note [a]Depicts design-level analysis with 85% environmental loading
[b]Depicts simplified ultimate strength analysis with 100% environmental loading

2.3 Nonlinear Ultimate Strength Analysis

As the results of the design-level analysis and simplified ultimate strength analysis revealed that some of the primary structural members, joints, and piles do not meet the assessment requirement, a higher level nonlinear ultimate strength analysis was carried out for eight directions of environmental loading. In this paper, results of nonlinear plastic collapse analysis [2] using USFOS [3] software have been discussed for assessing the ultimate strength of the jacket platform, and reserve strength ratio (RSR) values for the structure have been presented. The RSR is defined as

$$\text{RSR} = \frac{\text{Ultimate lateral load carrying capacity}}{100\,\text{year environmental condition lateral loading}}$$

The results of the ultimate strength analysis revealed that the structure is not able to withstand the environmental forces up to the target RSR [4] level of 1.323 for all the considered directions, primarily due to failure of Row-2 piles (refer Fig. 3) and X-brace joints present on Row-A and Row-B of the jacket structure, around a load level of 1.05 (refer Fig. 2).

Thereafter, a re-analysis for nonlinear ultimate strength check was carried out after considering conductors as piles for providing the lateral support [5]. The re-analysis results revealed that the structural adequacy of the jacket structure of platform still could not be documented for all the wave approach directions even after considering the conductors as piles.

The analysis results (both design-level and ultimate strength) revealed that the structure was having overstressed piles (predominantly Row-2 piles) and X-brace joints. The main reason for that is the change in the design regime (design hydrodynamic coefficients, hydrodynamic marine growth thickness, etc.) and installation of additional facilities on the platform over a period of time. All these factors have contributed to an increase in the hydrodynamic loading by more than 45%.

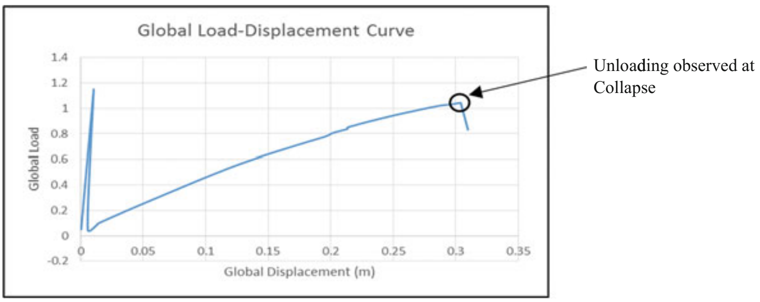

Fig. 2 Jacket structural collapse around a load level of 1.05

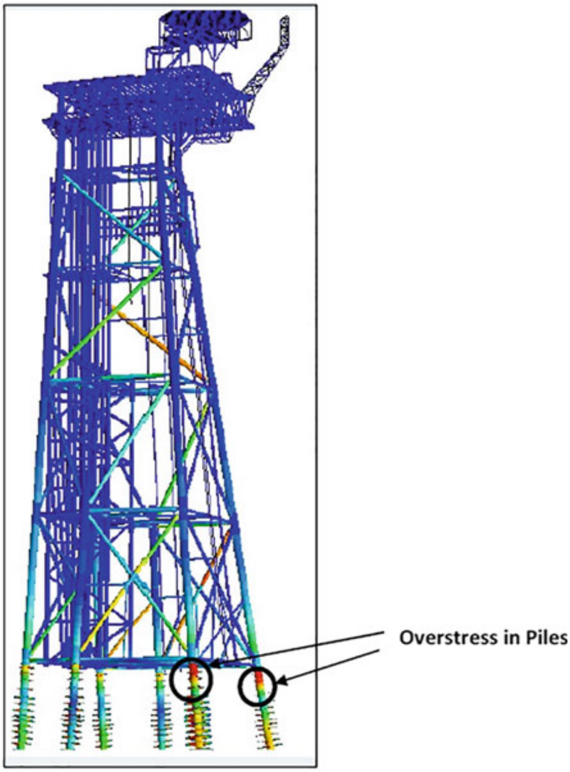

Fig. 3 Failure of row-2 piles, depicting plastic utilization

3 Additional Piles/Strengthening Requirement

3.1 Load Transfer and Load Distribution Mechanism for Additional Pile Arrangement

In view of the insufficient capacity of the jacket structure to withstand the design loading, an analysis study for installation of additional piles along with grouting of overstressed joints and members is contemplated.

The existing piles on Row-2 of the platform are found to be highly overstressed, and hence, additional piles have been contemplated to be installed near them. For ensuring proper load transfer, adequate strength pile connection needs to be designed, fabricated, and installed. The load distribution pattern needs to consider the fact that the vertical loads due to self-weight of the structure and topside (deck) loading would have already mobilized the pile-soil resistances for the existing piles, and the additional piles will only be contributing toward sharing the incident environmental loading. To assess the structural adequacy of the additional piles for sharing the environmental loading on the jacket structure, two separate analysis studies (with 100% loading) have been carried out:

1. In-place design-level analysis with only existing piles considering only gravity loads (100%)
2. In-place design-level analysis with all piles (incl. additional piles) considering only environmental loads (100%)

The effects on the support system (pile-soil system) were then combined to achieve the pile head loads for ascertaining the pile material utilization and soil capacity utilization (refer Table 3). It is important to note that pile material utilization is of utmost concern as the jacket structure was having highly overstressed piles in its original condition. An iterative procedure was adopted for the selection of adequate pile size for providing sufficient support capacity, and therefore, pile sizes ranging from 60 in. up to 84 in. were checked for. Following this procedure, it was finally proposed to install four 84 in. (2.134 m) additional piles on Row-2 of the platform (two additional piles each at pile location A2 and B2); thereby all the piles been found to meet the requisite strength requirements.

Additionally, the exact new pile intra-spacing and distance from existing piles on Row-2 (refer Fig. 4) will have to be ascertained for assessing the load distribution and pile group effects. The proximity to which the installation barge could approach the platform and the obstruction posed due to the structure deck needs to be duly considered.

Table 3 Factor of safety for extreme storm condition for both compression and pull out for well platform

Pile No.	Location	Min. FOS in compression[a]	Min. FOS in pull out[a]	Max. pile UC[a]
1	A1	2.46	3.51	0.408
2	B1	2.08	4.08	0.683
3	A2	2.88	7.51	0.647
4	B2	2.63	20.58	0.925
5	SKA	1.93	5.05	0.246
6	SKB	1.55	5.83	0.532
7	A2 (NP1)	2.56	1.95	0.302
8	A2 (NP2)	3.24	2.29	0.262
9	B2 (NP1)	3.18	2.25	0.276
10	B2 (NP2)	2.23	2.23	0.303

[a]Sump-pump caisson and future riser protector considered to be removed

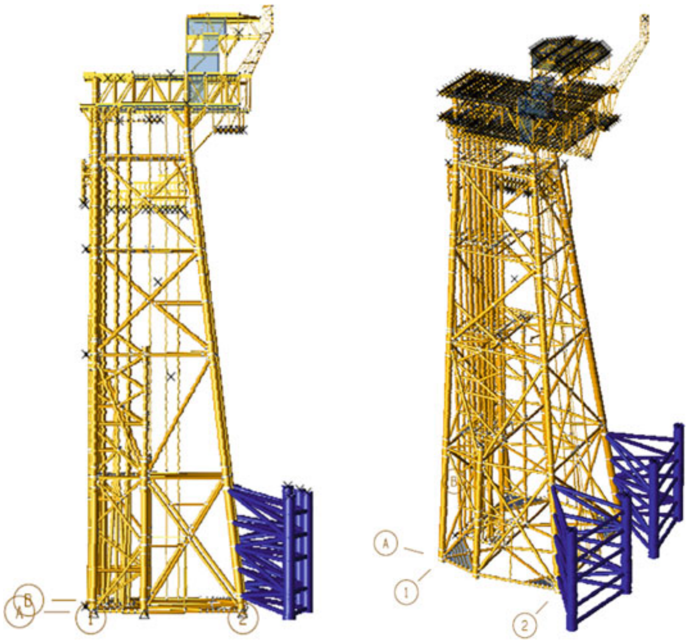

Fig. 4 Structural model with additional piles

3.2 Proposed Additional Pile Details

Number: 4
Size: 2.134 m (84 in. outer diameter) × 0.065 m (Thickness)
Vertical Penetration below mud line: 45.5 m

It is to be noted that after carrying out the strengthening of the jacket structure with additional four piles on Row-2 of the structure, the load redistribution has effectively resulted in the reduction of stresses in some of the adjacent members and joints , e.g., the Row-A and Row-B primary X-brace joints (b/w EL (−) 52.76 m and EL (−) 77.455 m) were now found to be stressed within permissible limits.

3.3 Grouting Scheme

One of the primary structural members and two primary structural joints were found to be overstressed after carrying out the analysis with additional piles; so, strengthening of these components has been proposed. The analysis has been carried out after considering the strengthening of the member 0001-404L with adequate strength grout [6] (Fig. 5), the results of which reveal that the member is stressed within the permissible limits. The results of the re-analysis performed after

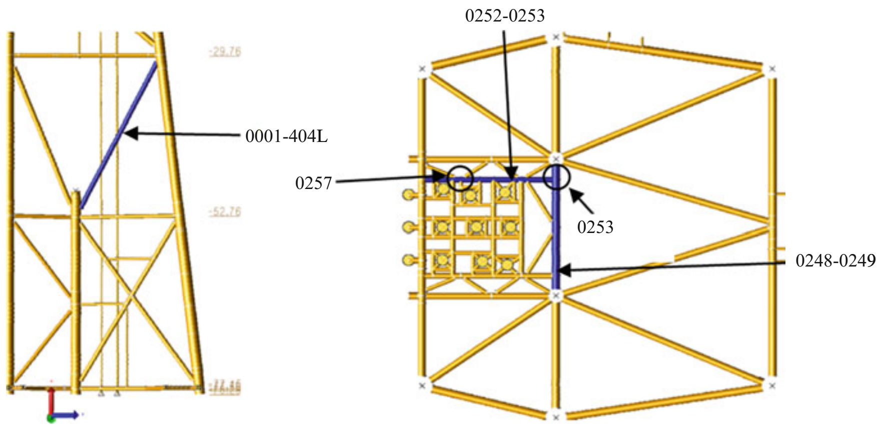

Fig. 5 Structural components proposed for grouting (as highlighted)

considering the strengthening of the respective chords for joints 0253 and 0257 with adequate strength grout (Fig. 5) reveal that the structural joints 0253 and 0257 are stressed within the permissible limits.

4 Conclusion and Recommendations

The results of the structural analysis show that in the original condition, even after incorporating the suggested mitigation measures, the jacket structure of the platform did not meet the structural adequacy requirements primarily due to overstressed Row-2 piles and X-brace joints.

In view of the same, it has been contemplated to install four additional piles near Row-2 of the platform. A design-level analysis has been carried out with additional piles proposed to be installed on the platform. The structural adequacy of the platform could be documented for all the considered environmental directions subject to the following mitigation/strengthening measures:

1. Removal of sump and pump casing,
2. Non-consideration of future riser protector on Row-2 of the structure,
3. Installation of additional four 84″ (2.134 m) piles on row-2 of the platform (two each at A2 and B2), and
4. Grouting of primary structural member 0001-404L and primary joints 0253 (Joint Chord member 0248-0249 to be grouted) and 0257 (Joint Chord member 0252-0253 to be grouted)

The additional pile-jacket connection details along with final additional pile penetration below mud line, and members grout properties will be required to be designed while carrying out the detailed engineering. From above, it can be concluded that old-age platforms can be re-qualified with the implementation of appropriate mitigation measures adopted after carrying out detailed nonlinear assessment of the structure. These structures can continue production of hydrocarbons without pressing the need of platform abandonment process or installation of new platforms.

Acknowledgements We acknowledge the support and resources provided by ONGC required for carrying out this study. The study has been immensely beneficial in understanding the pertinent issues relevant to the structural behavior of jacket structures and is of vital importance in purview of ONGC's operational requirements to carry out life extension studies of existing platforms. We extend our sincere thanks to Shri C. Tandi, ED-HoI, IEOT-ONGC for his generous support and encouragement. We are also immensely grateful for the continuous motivation received from Shri Dinesh Kumar, GGM (Civil)-Head of Structures Section, IEOT-ONGC.

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