Structural Design of Float-over Type Fixed Offshore Platforms – A Disruptive Method Using Knowledge-based and AI-aided Technique

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ABSTRACT

This paper proposes an AI-aided and knowledge-based method to configure and size of float-over type fixed offshore platforms considering only a few basic input parameters when topside details are unavailable. The new technique bypasses the commonly adopted sequence of structural sizing. The computer program developed for the purpose generates a detailed structural analytical model and summarized material take-off (MTO) for the structural steel. The built-in knowledge of the program determines the size of the deck structure considering the available experience on the equipment layout. The program then generates the size of the deck and jacket members based on existing engineering knowledge on structural design. The present design is considered preliminary, as all mandatory structural analyses will have to be performed later when equipment details are available. However, preliminary structural analyses can be performed immediately with the equivalent and conservative uniformly distributed applied loads on the deck. The analytical model can be updated with a single click when the equipment details are available and provided in a tabular format. During detailed design at various stages of a project, the design may require minor update without considerable impact to the generated MTO. Numerical studies show three examples of auto-designed structures at up to 50m water depth that can withstand omnidirectional environmental forces due to 20.0m high waves. Structural design is performed using API RP2A working stress design method. The results show adequacy of the structure with the required minimum reserve strength and acceptable values of natural time periods.

Keywords: Preliminary design of jacket-type offshore structures; float-over platforms; disruptive design technique; use of machine learning algorithm; automatic generation of structural MTO; quantum reduction of design time.

1   INTRODUCTION

Structural design of fixed offshore platforms is performed through a series of structural analyses to withstand design loads due to in-place and installation conditions. Size of an offshore platform depends on several factors such as water depth, design environmental parameters, geotechnical properties of the seabed, design seismic parameters, various types of equipment, piping and utilities, operational requirements and the installation method. Traditionally, structural design of new offshore platforms starts with an assumed deck size followed by a preliminary equipment layout. Based on the assumed deck size and number of levels, a preliminary jacket and deck configuration including sizing of the members are assumed in the form of an analytical model. Structural response for each loading condition is checked against the design code-specified limiting criteria. Final design is made after completing several rounds of analyses incorporating changes in each analysis. Alternatively, an existing design is modified which is cumbersome in most cases. Both design approaches are time-consuming process and often, structural design could not be completed because of the lack of information from non-structural disciplines until the late stage of engineering activities. Hence, the preliminary design must include appropriate conservatism as applicable for various types of structural analyses. In some cases, however, detailed information about the topside facilities may not be necessary that govern only the local design or partially govern the global design, as the structure must be built with the minimum strength and ductility to withstand all load conditions.

Classification: Public

Well-developed methods are available in the relevant design standards (API RP 2A, 2EQ, 2GEO, AISC, ISO 10901-1) for structural design of fixed offshore platforms based on several decades of research on offshore structures behaviour under various load conditions. Commercially available software for analyses of offshore structures have already implemented the benefits of these common design methods. These computer programs include automated design tools to save time and minimize iterative design calculations. Notwithstanding the above, structural design of offshore platforms require a substantial amount of manual involvement mainly because of –

    (i)   Requirement of creating an analytical model before carrying out detailed calculations for several load conditions
    (ii)   Possibility of an improvement in the previous design
    (iii)   Nonexistence of a unique design for the given design parameters
    (iv)   Change in design parameters from one project site to another. For example, difference in water depths between two sites of the same geographical location and for the same topside facilities may result in significantly different structural configurations for the two locations.

Kling et al. (2019) presented a method on structural optimization by using genetic algorithm. Qian et al. (2023) presented a conceptual design of offshore jackets using self-developed database for offshore wind turbines (OWT). Häafele and Rolfes (2016) proposed a method for design of the OWT substructures as a mathematical optimization problem. Panagiotou et al. (2023) proposed the design of the OWT substructure as a multi-objective optimization problem and used artificial intelligence (AI) to discover multiple optimal solutions. Recently, the present author (2024) has introduced a semi-empirical method to perform automatic structural design of fixed jacket-type conventional offshore platforms using available knowledge on equipment layout and structural design. Float-over type fixed offshore platforms require a different design approach due to imposed constraints by the requirements of transportation barge because of the heavier deck and jacket in comparison with the conventional fixed jacket-type offshore structures. This paper highlights automatic design of float-over type fixed platforms by using knowledge-based technique and machine learning (ML) algorithm of AI for the deck and jacket sizing.

The present work has endeavoured to develop a method that automates most of the initial structural engineering activities to create a detailed analytical model at the conceptual stage of the project. The computer program developed for this purpose requires only a few input parameters, which are kept as simple as possible and discussed in the following section. Based on these simple inputs, the program automatically determines the size of the jacket legs & piles, prepares the structural configuration of the jacket and deck, chooses the sizes of various members of the structure and generates various other details along with the main structure such as boat landing, mudmat, crane pedestal, flare boom, helideck, jacket launch truss, number of anodes for cathodic protection, etc. The program also suggests the required size of the deck transportation barge which can be overwritten by the user. Design of the structure will be made without carrying out any structural analysis, however, ensuring the adequacy of the structure to withstand all applicable loads based on design experience. The auto-designed structure, however, may require local modifications during detailed design due to some load conditions such as placement of a heavy equipment on a small footprint of the deck. As required by all design specifications, the design must be verified with the actual equipment loads considering the final equipment layout and the usual local design checks should also be performed, which are not available in the global analyses.

2   PROPOSED METHOD

2.1   Input parameters

The auto-design program requires the following input data:

    (i)   Gross weight of the topside facilities excluding the deck structure
    (ii)   Water depth
    (iii)   Maximum wave height
    (iv)   Design seismic coefficient
    (v)   Axial capacity of pile for various diameters and penetrations (to be provided in a table from the available geotechnical report)

2.2 Determination of the sizes of deck and jacket

Dimensions of the deck (length and breadth), number of decks and its elevations are decided by the program based on the given input parameters. The method to determine the deck size is highlighted in the reference paper (Chatterjee, 2024). Size of the deck can be determined with the help of two methods - (i) by preparing equipment layout drawings considering all multidisciplinary inputs including the provision for future equipment/facilities and additional space for operational and safety needs such as maintenance space, escape route and muster area, (ii) listing down and summing up of all equipment footprints area and maintenance spaces and then adding the same with the space required for operational and safety needs. The gross weight of all equipment and facilities (commonly called as topside(s)) can be estimated similarly by adding up the individual equipment weights. In general, heavier topside implies compact equipment and piping layout with efficient use of the 3D (three dimensional) space of the deck. In the absence of a given deck size, the program uses empirical relations to estimate the required deck area from the given weight of the topsides. Discussion on the empirical parameters is excluded from the scope of the present paper. The calculated deck area must be verified with the outcome of the above two methods, whenever the details are available.

Jacket configuration is determined after considering the size of the deck and the given input parameters. The size of the piles is calculated from the estimated environmental loads as highlighted in the following section. All members of the deck and jacket are sized considering the minimum requirements, including design code checks, member utilization due to anticipated loads and specific requirements for the fabrication and installation of the structure.

2.3 Method to estimate environmental loads

In the absence of a structural model to calculate the environmental loads on itself, a database is utilized to estimate the environmental loads. The database consists of the environmental loads expected on different sizes of float-over type fixed offshore structures corresponding to 100-year return period. The database is generated from several hundreds of structural analyses. These analyses cover a wide range of jacket configurations and size, jacket leg diameter, leg batter and environmental (wave, wind and current) data. Machine learning algorithm is used to predict the environmental loads for the new structural configuration, size and environmental data.

2.4 Structural analysis for design environmental loads

For design verification, all structural analyses are performed by using the third-party commercial software SACS (2023). The auto-design program generates a detailed SACS analysis model. In addition to the weight of the topside, environmental loads (wave, wind and current), buoyancy and marine growth weight are applied to the analytical structural model. Wave load on the structure is conservatively increased by 10% to account for the anodes, risers and caissons which are not explicitly modelled in the SACS file. Geotechnical data for the seabed soil profile are considered from the available report for an actual offshore location. Gravity loads due to weight of the equipment, piping and other facilities are applied on the structure as uniformly distributed load (UDL) for the numerical study. A linear and elastic structural behaviour is ensured by restricting (i) the computed member stresses within the code-specified allowable limits and (ii) the computed horizontal and vertical deflections of the structure small. However, nonlinear pile-soil-interaction within the seabed is considered by utilizing the available data for lateral, axial and end bearing curves from the given geotechnical data.

Coordinate axes used for the structural analyses and the direction of wave approach are shown in Fig. 1 (typical) where the geometrical centre of the jacket is chosen as the origin of X and Y-axis and MSL (mean sea level) is considered as the origin of Z-axis (in vertical direction). Environmental loads on the structure will be generated using omnidirectional metocean data for the purpose of numerical study. Environmental load directions are considered at 30° intervals resulting in a total of 12 load cases for each of the 1-year (operating) and 100-year (extreme) loads. All structural members (tubular members, piles, beams and plates) are to be checked as per the provisions of relevant design codes (API RP 2A WSD and AISC-ASD) to satisfy the member and joint unity checks. Factor of safety (FOS) for the compressive load on piles is maintained above 2.0 and 1.5 for the load combinations involving 1-year and 100-year return periods respectively.

2.5 Limitation of the auto-design program

The auto-design program is presently valid for offshore structures at 10m to 50m water depth, a maximum wave height of 20m and considers 4, 6 and 8-legged jackets depending on the size of the deck. The program considers only driven-through-leg piles i.e. no skirt pile at present. The program determines the jacket and deck configurations, deck size and the size of the members based on the given parameters as mentioned in the previous section. The automatic design of the jacket launch truss can be performed for 8-legged jacket only.
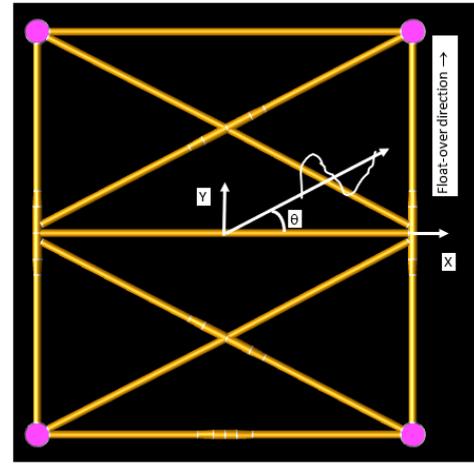
3 NUMERICAL EXAMPLES

3.1 Example - 1

Figure 1: Plan view at jacket horizontal framing level showing the model coordinate system

The first example shows an auto-designed 4-legged float-over platform (Fig. 2) using the following input parameters:

Total weight of the topside facilities	= 2000 t	(tonne or MT)	(excluding the structure)
Water depth	= 20 m		
Design wave height	= 10 m		
Design seismic coefficient	= 0.35g	(g = acceleration due to gravity)	

Axial capacities of the piles for various diameters are provided as input to the program (Table 1). Size of the mudmat can be calculated from the bearing capacity value provided as input. The values of the axial capacities of the piles and the mudmat bearing capacity can be automatically generated by the program also from the built-in database of the available sites. Table 2 shows the extracted summary of the design including the structural MTO as generated by the program. The number of anodes is calculated by providing the cathodic protection design parameters in a separate table. The program has selected 1.372 m diameter piles with 69.4 m of seabed penetration. The deck configuration is decided by the program based on the assumption of a default barge width which can be changed if the transportation barge details are available.

Design verification is made by performing in-place analysis with available pile-soil-interaction data. Environmental data used for the analysis are indicated in Table 3. In absence of the equipment details, the program provides an in-place analysis model with equipment weight applied as UDL as default. An equivalent UDL of 10 Pa are applied on the lower and upper decks and 15 Pa on the middle/main

Figure 2: Four-legged platform

deck as the equipment loads for the purpose of the design adequacy check. 75% of this total applied UDL is considered in all load combinations for checking the global design. The application of the UDL results in a total of 4945 t of applied gravity load on the structure (due to equipment and other facilities) against the design value of 2000 t. The program can automatically update the analytical model if the actual weight of the equipment, location of its centre of gravity and the footprint details are provided in a tabular format.
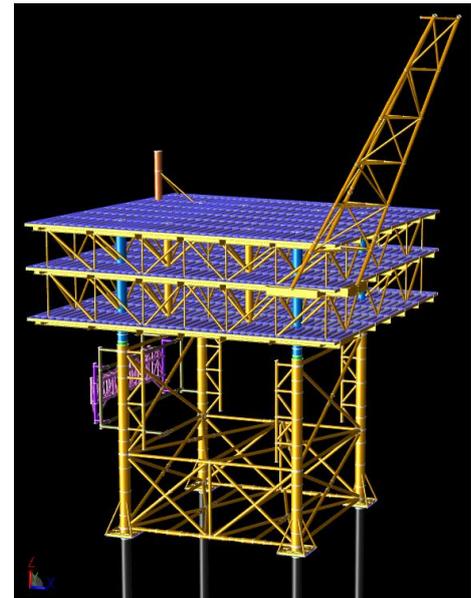
Table 1: Axial capacities of piles

Diameter (m)→	2.286	2.134	1.981	1.829	1.676	1.524	1.372
Capacity (MN)	75.0	69.0	60.0	58.0	55.0	50.0	45.0
Penetration (m)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Capacity (MN)	59.0	52.0	48.0	45.0	42.0	40.0	35.0
Penetration (m)	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Capacity (MN)	40.0	35.0	32.0	30.0	27.0	25.0	22.0
Penetration (m)	40.0	40.0	40.0	40.0	40.0	40.0	40.0

Table 2: 4-Legged float-over platform: basic design parameters and generated MTO

Water Depth	20 m
Weight of topside (excl. deck structure)	2000 MT
Maximum wave height	10 m
Seismic Coefficient	0.35 g
Deck size: DLx, DLy (rectangular)	40x38 m
Jacket dim. at top of pile: JLx, JLy	26x24 m
Lower Deck Elevation w.r.t. Water Line	12.2 m

Items and its expected weight	in "MT"
Deck primary beams	1079.4
Deck beam node plates & stiffener plates	107.9
Deck secondary beams	260.5
Deck tubulars	499.1
Deck plates	310.2
Expected total weight of deck	**2257.1**
Jacket	383
Piles (Dia = 1.372m, pen. = 69.4 m)	548.4
Boat landing (incl. support stubs)	93.8
Mudmats	17.7
Handrails	15.0
Staircases	7.6
Misc. steel weight (without construction/installation aids)	97.3
Expected total weight of Structural Steel	**3420.3**
Number of anodes (250 kg net weight each)	61
Aprx. addl. draft of deck trnsp. barge = 3.4m for a 76.2m long barge with 4736MT of cargo weight	

For All Active LCs
Mem Result: Combined UC

1.000+
0.900 - 0.999
0.850 - 0.899
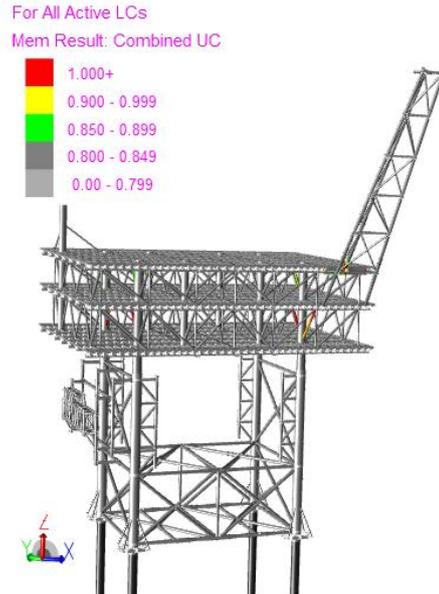0.800 - 0.849
0.00 - 0.799

Figure 3: Member UCR plot for 4-legged platform

Table 3: Omnidirectional Environmental data

Environmental condition	Wave height (m)	Wave period (s)	Current speed (m/sec) at 0, 25, 50, 75 and 100% of water depth from mudline	Wind speed (m/s) at 10 m above the MSL
1-year return period	8.0	9.3	0.2, 0.3, 0.3, 0.4, 0.6	18.0
100-year return period	10.0	10.5	0.3, 0.4, 0.5, 0.7, 1.0	27.0

Figure 3 shows the member unity check ratio (UCR) plot. Referring to the figure, a few deck bracing members are exceeding the unity check. The failures are mainly due to large axial stress because of conservative UDL applied on the deck and therefore may be ignored. A few beam member failures may be ignored also as the same can be addressed in the local design considering the provision of node plates and stiffener plates. Table 4 indicates the maximum lateral deflections of the deck along X and Y directions. Both the deflections are found to be within the allowable limit. All tubular joints are observed to pass the code check for both the applied loads as well as due to member strength requirements. In case of joint failures, these checks should be left to the detailed engineering stage during the actual project implementation as all the failed joints may not require higher-thickness cans.

3.2   Example – 2

The second design is generated for a topside weight of 3000 t and 15 m of design wave height at 30 m water depth. The program gives a design with 6-legged platform. The program has selected 1.676 m diameter piles with 62.5 m seabed penetration for the design.

Classification: Public

Table 4: Maximum horizontal deflections of the deck (for 4-legged platform)

Env. Criteria (return period)	X-deflection (cm)	Y-deflection (cm)	Limiting deflection (L/200) (cm)
100-yr	16.3	9.6	23.0

Wave heights corresponding to the extreme and operating conditions are considered as 15 m (associated period = 11.5 s) and 10 m (10.5 s) respectively for the in-place analysis. Other environmental data used for the analysis are indicated in Table 3. Figure 4 shows the member UCR plot. The plot shows a few minor failures at the deck tubulars locally that may be ignored due to conservative applied loads. Other local failures, if any, can be addressed during detailed design. The maximum deck deflections are obtained as 14.1 cm and 15.2 cm for the X and Y directions respectively, which are well within the allowable limit.

3.3 Example - 3

The third design is generated for a 10000 t of topside weight and 17 m of design wave height at 48 m water depth. The program generates a design with an 8-legged platform having 1.981 m diameter piles and 80 m seabed penetration (Fig. 5).

For All Active LCs
Mem Result: Combined UC

■	1.000+
■	0.900 - 0.999
■	0.850 - 0.899
■	0.800 - 0.849
■	0.00 - 0.799

Fig. 4 – Member UCR plot for 6-legged platform

Wave heights for extreme and operating conditions are considered as 17 m (associated period = 11.8 s) and 10 m (10.5 s) respectively for the in-place analysis. Other environmental data used for the analysis are considered from Table 3. Figure 6 shows the member UCR plot that shows only minor local failures at the base of the flare boom. This local failure can be addressed in the local design check, if required for the final design.

The deck is also checked for loadout condition by assigning pinned supports at the bottom of the internal deck columns. In absence of the actual equipment loads, the same UDL (as in the in-place analysis) is conservatively considered for the loadout analysis and 75% of the UDL is combined with the gravity load of the deck structure for the loadout analysis. Total applied UDL = 13940 t (against the design topside weight of 10000 t). Figure 7 shows the member UCR plot which indicates no failure of the deck members. The effect of the shift in centre of gravity of the topside on the UCR can be verified only for a real project with the availability of the equipment details.
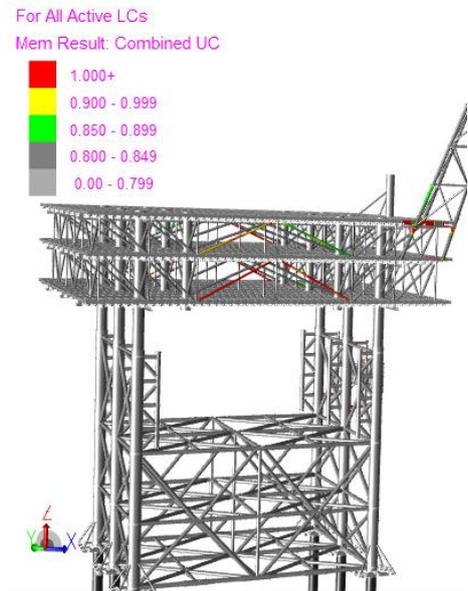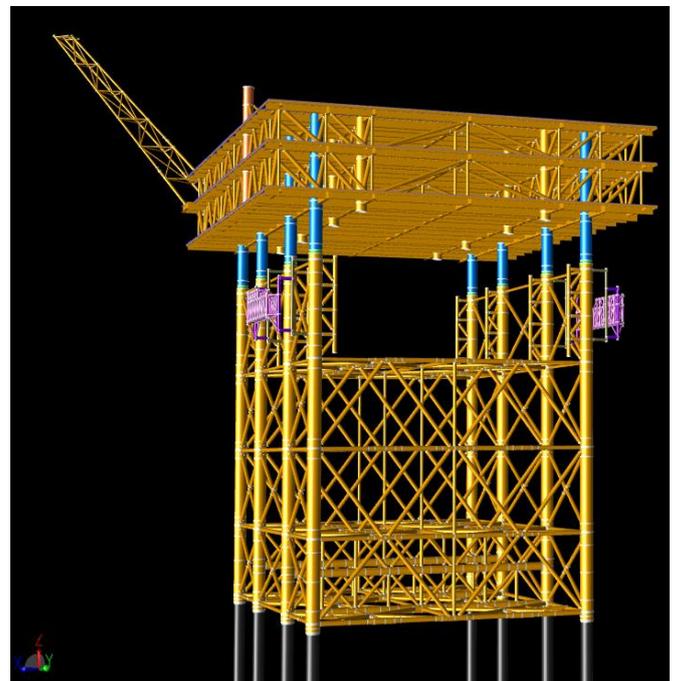

Figure 5: Eight-legged float-over platform

3.3.1 Dynamic susceptibility checks for the auto-designed structures

To study the sensitivity of the proposed structure under dynamic loads, free vibration analyses are performed for all the three designs. 50% of the topside weight (other than structural weight) applied as UDL is converted to mass for dynamic analysis so that the total non-structural dynamic masses on the three decks are obtained as 3297 t, 4995 t and 9290 t for the 4, 6 and 8-legged structures respectively. Table 7 shows the first three natural time periods of the three structures. The fundamental time periods for all three examples are below 3.0 seconds implying that the structures are not expected to be dynamically sensitive.

Table 7 - Natural time periods from free-vibration analysis

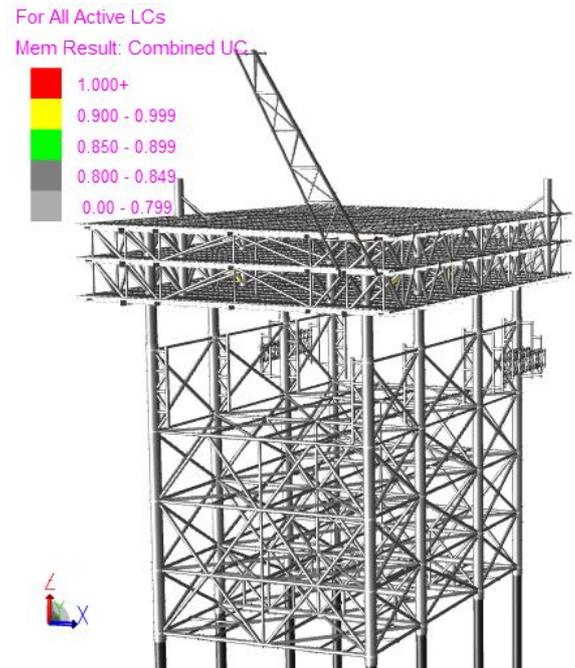| Platform type	Mode-1	Mode-2	Mode-3
4-legged	2.63	1.48	1.41
	Lateral mode in X-Z plane	Torsional mode	Lateral mode in Y-Z plane
6-legged	2.14	1.31	1.17
	Lateral mode in X-Z plane	Lateral mode in Y-Z plane	Torsional mode
8-legged	2.591	1.56	1.48
	Lateral mode in X-Z plane	Lateral mode in Y-Z plane	Torsional mode

The highlight of this exercise is that the auto-design program generates a dynamic-analysis-ready model (without the requirement of further modification of the static model) that can be immediately exploited for the mode-shape extraction and subsequent dynamic analysis to verify the design.

Figure 6: Member UCR plot for the 8-legged platform

4 CONCLUSIONS

Based on the above discussions and numerical results, the following conclusions can be drawn –

1. Machine learning algorithm and knowledge-based AI is successfully used to determine the size of the float-over type fixed offshore platforms. The proposed method takes only a few seconds to provide a preliminary design of the float-over type offshore structures.

2. The auto-design program creates a detailed structural model by providing only a few simple input parameters when information on the topside facilities is unavailable. The analytical model can be quickly updated with a single click when equipment details are available and provided in a tabular form. Only local changes may be required during detailed design due to application of the actual equipment details.

3. Enormous saving of engineering time can be made without spending weeks, sometimes months because of the inter-disciplinary issues in preparation of the first-pass analytical model in working condition. The built-in knowledge of the program bypasses the conventional design sequence and provides a design that is found to be adequate for both the space and strength requirements.

4. Immediate availability of a structural model will greatly help the EPCIC (Engineering, Procurement, Construction, Installation and Commissioning) Companies to initiate subsequent multidisciplinary engineering activities such as modelling of the equipment, piping and utilities followed by the development of the tertiary steel and structural fabrication details.

5. The program can be easily utilized to prepare a feasibility study and estimate the associated costs by creating various options of structural configurations and the corresponding MTO in a matter of few minutes. This feature will help the Operators and Consultants in significantly reducing the initial efforts during estimation of the project cost.

The method adopted in developing the present technology is largely generic. Minor change in the design is however, expected for different geographical regions due to change in the metocean criteria and geotechnical parameters of the seabed.

The purpose of the above numerical examples is to demonstrate the ease of generating a detailed structural model by providing a very few input parameters. Other analyses including the demonstration of the reserve strength for the auto-designed structures are not presented in this paper. Examples of real-life designs generated by the auto-design program are not available yet.
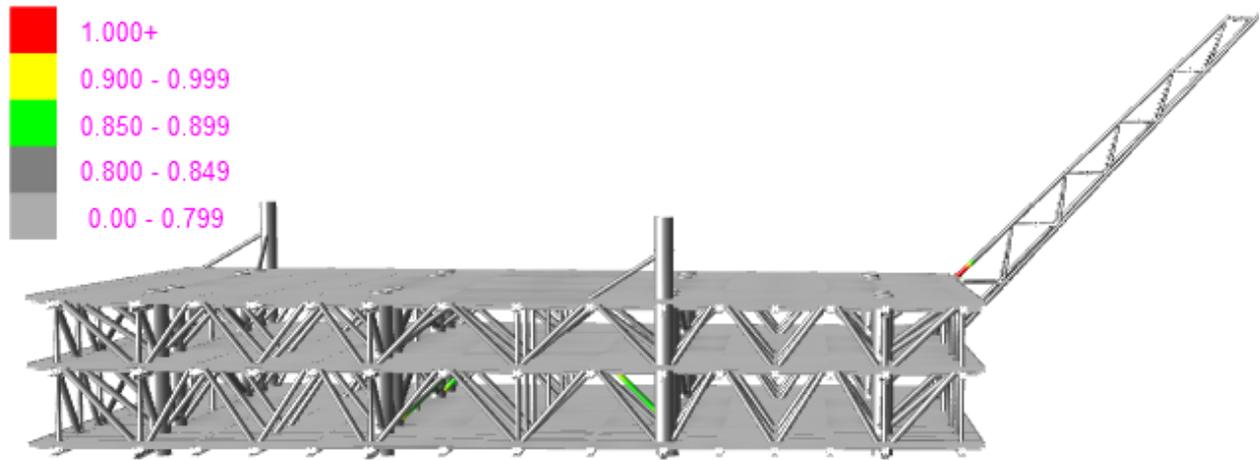

Fig. 7 – Member UCR plot for the 8-legged platform deck due to loadout condition

References

AISC Manual of Steel Construction Allowable Stress Design, 14th Edition, 2015.

API RP 2A WSD 21st Edition, Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, 2014.

API RP 2EQ, Seismic Design Procedures and Criteria for Offshore Structures, 1st Edition, 2014.

API RP 2GEO, Geotechnical and Foundation Design Considerations, 2014.

Eli Yecheskiel Kling et al. Automated Jacket Design, The 29th International Ocean and Polar Engineering Conference, Honolulu, Hawaii, USA, 2019, ISOPE-I-19-382.

Emmanouil Panagiotou et al. Explainable AI-Based Generation of Offshore Substructure Designs, The 33rd International Ocean and Polar Engineering Conference, Ottawa, Canada, 2023, ISOPE-I-23-045.

Han Qian et al. Data-based Conceptual Design of Offshore Jackets Using a Self-developed Database, The 33rd International Ocean and Polar Engineering Conference, Ottawa, Canada, 2023, ISOPE-I-23-154.

ISO 10901-2. Petroleum and Natural Gas Industries – Specific Requirements for Offshore Structures, part 2 – Seismic Design Procedures and Criteria, 2004.

Jan Häafele and Raimund Rolfes. Approaching the Ideal Design of Jacket Substructures for Offshore Wind Turbines with a Particle Swarm Optimization Algorithm, The 26th International Ocean and Polar Engineering Conference, Rhodes, Greece, 2016, ISOPE-I-16-143.

Prabir Kumar Chatterjee. Disruptive Structural Design Technique for Fixed Jacket-type Offshore Platforms, Offshore Technology Conference Asia, Kuala Lumpur, Malaysia, 2024, OTC-35001-MS.

Prabir Kumar Chatterjee. Structural Design of Fixed Jacket-type Offshore Platforms - A Disruptive Technique, Asia Pacific Oil & Gas Conference and Exhibition, 15 - 17 October 2024, Perth, Australia.

SACS Offshore Structures software. CONNECT edition Version 23, 2023.