Middle-East Journal of Scientific Research 13 (10): 1351-1358, 2013
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2013.13.10.1219

Nonlinear Analysis of Offshore Helidecks Due to the Helicopter Emergency Landing Loads

[1]Mohammad Vaghefi, [2]Hassan Bagheri and [3]Saeed Reza Mohebpour

[1]Department of Civil Engineering, Persian Gulf University, Boushehr, Iran
[2]Islamic Azad University, Boushehr Branch, Iran
[3]Department of Mechanical Engineering, Persian Gulf University, Boushehr, Iran

Abstract: Nowadays, as before, some transportation still is performing by helicopters at offshore facilities and therefore the use of helicopters requires the installation of the landing structures. Basically helidecks are flat plates with primary and secondary beams, that generally designed by static linear analysis. Since there's always the probability of a helicopters emergency landing in a lifetime of such structures, evaluation of structural performance to achieve structural capacity beyond the elastic range by non-linear analysis can create new approaches in the design codes of offshore facilities. Hence, this paper focuses on the response of this structure using the nonlinear static pushover analysis under vertical and lateral loads caused by helicopters emergency landing.

Key words: Offshore helideck · Emergency Landing · Helicopter · Nonlinear static analysis

INTRODUCTION

Nowadays, with increasing of oil and gas field's development and also installation or commissioning of related offshore technology, the needs for communication and air access to these facilities has also increased. Considering the space limitation in offshore installations, the helicopters would be an appropriate machine to accelerate the transportation. Also Helidecks on these installations would operate such as an airport, so this additional structure must be designed in a way to have a proper interaction with platforms. Recently, the International Association of Oil and Gas process has reported numerous accidents and injuries caused by helicopters. In 2000 the HSE Department of the United Kingdom has also reported 19 cases of fatal crashes at offshore in the West Europe; three cases were happened on offshore platforms related to emergency landing [1]. These events concern us to investigate on the helideck response due to the emergency landing impact. Despite the approaches of current design codes have changed from design-based on force method to design-based on performance method, the helideck design codes still recommend their users to use the force method. Therefore, by using nonlinear analysis to review the capacity of structure in the elastic range, estimating its resistance and assessment of the current codes, could have appropriate results for the next generation of design codes.

Research Review: Investigated researches on the decks and analyzing the great impact loads on such structures which the designers could use as codes, perhaps the first time in 1960 has started by Clarkson as "Tests on flat plate grillages under concentrated loads". This load has been applied directly on the deck's stiffeners [3]. Also in October 1963 Harding has found a method to measure wheel loads caused by the helicopter. He considered the emergency landing and failure of the helicopter landing gears [4].

In 1981, Jackson and Freeze investigated to create design method for deck structures under wheel loads. The results of their investigation lead to invent graphical method for structural design [5]. In 1990, GARRON investigated on the helicopter induced deck loads and the results shown the different approach in the vibration response of such structures [6]. Recently at 2005, an investigation of the wind environment over

Correspondence Author: Mohammad Vaghefi, Department of Civil Engineering, Persian Gulf University, Boushehr, Iran.

the helideck of a model of an offshore jack-up platform was carried out by Qiang and Zhifu in an atmospheric boundary layer wind tunnel. Hot-wire anemometry was used to measure the velocity distribution over the helideck for five different wind directions. The results showed that the mean velocities and root-mean-square values of the fluctuating velocity are quite different under various wind directions. Flow visualization by smoke-wire technique is also presented [7]. Also, an investigation carried out by Vaghefi and Bagheri in 2010, determined that the results of SACS software is acceptable in non-linear analysis compared with other finite element software [2]. This study uses SACS software and pushover analysis to review the helideck structural response under emergency landing condition.

Necessity of Nonlinear Analysis: The purpose of nonlinear analysis is structural analysis considering nonlinear behavior of structural components due to material nonlinearity, effects of geometric nonlinearity and cracking [8]. Nonlinear analysis of structures has become increasingly important in the study of structural response to hazardous loads. In recent years, the requirements of structural analysis have become more challenging. Some of the reasons for these challenges are as follows [9]:

- New approaches to the design of structures for earthquakes and other hazardous loads are based on structural performance and use fragility functions as measures of performance. Such fragility quantification is carried out with respect to predefined performance limit states describing the condition of the structure in relation to usability and safety. Often, the limit states used in special designs are well beyond linear elastic behavior, in many cases approaching collapse conditions.
- Structures in areas of low to moderate seismicity have traditionally been designed for gravity loads. Evaluation of such structures under more stringent loads prescribed by modern codes requires estimation of their strength and ductility reserves at various levels of ground motion.

So using a nonlinear analysis method such as pushover could carry out the ultimate strength of structures under special loads. Pushover analysis of structures is a static non-linear analysis under vertical or lateral loads which gradually increase. The aim of this method is to estimate the expected behavior of structural systems by using incremental loads up to failure. This method is a step by step analysis. In each step, the reduced stiffness of members that caused by arisen the plastic hinges will consider for next step. One of the most important results of this analysis is the capacity curve which will be created by specifying forces against displacement in each step; this curve is known as pushover curve [8, 9].

Emergency Landing Load: Basically the helidecks are flat plates with primary and secondary beams which generally designed by static linear analysis [16]. In general for analysis of such structures the following loads should be considered; dead and live, wind, snow, traffics, heavy and emergency landing loads, helicopter at rest and etc [12, 13, 16]. This study concentrates on the emergency landing loads which expected only once in a lifetime and to result from such serious events as loss of power, major pilot mishandling, or fouling of installation equipment upon landing or take-off [16].

The take-off and Landing area should be designed for the heaviest and largest helicopter anticipated to use the facility. Helidecks must be resistant against the following helicopter landing loads;

- Vertical Dynamic load Due to Landing
- Lateral load Due to Landing

Vertical Dynamic Load Due to Landing: Impact of landing gears should be applied at two points of the structure simultaneously and not to be less than 75% of maximum take-off weight (MTOW) of the helicopter which is reported by the manufactures (Figure 1). Distance (e) should be selected according to the type of expected helicopter [17, 18].

The total vertical force (F_V) from helicopter during landing shall be taken by equation 1; which M is maximum take-off weight of helicopter and C_g is the emergency impact coefficient [16]. C_g (emergency impact coefficient) shall be taken in a range of 2.5~3.00 for, this range shows the difference between codes approaches for emergency impact coefficient. In addition some codes recommend considering Structural Response Factor (SRF) for intensifying the dynamic impact [13, 18, 19].

$$F_V = SRF \times C_g \times M$$
$$SRF = 1.3 \qquad (1)$$

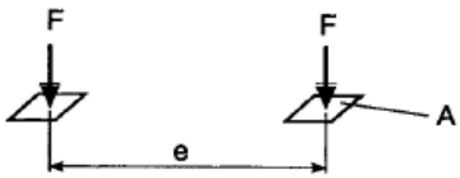

Fig. 1: Wheel or Skid loads at two point simultaneously [16].

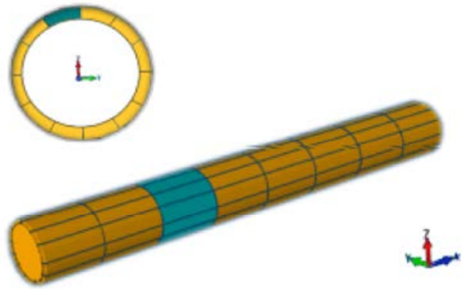

Fig. 2: Beam element and its sub-segments and sub-elements at SACS software [2].

Lateral load Due to Landing: In order to apply the lateral loads due to helicopters landing could use the half of MTOW of the expected helicopter [12, 19].

Sacs Approaches in Nonlinear Collapse Analysis: This software has the ability to offer a wide array of analysis and design to its user and generally could solve the finite element analysis from a simple two-dimensional frame to complex three-dimensional frames. This software is also able to solve non-linear static analysis and report the structural responses caused by wind, sea waves and other related loads. One of the important features of this module is analysis by considering the large deflection, elasto-plastic and nonlinear finite element system for structures [14].

In this study SACS has been selected according to its Pervasiveness in analysis and design of offshore structures and also its acceptable result in nonlinear static analysis [2].Beam element stiffness is developed using second order effect with nonlinear material properties. Each beam is automatically discretized by using sub-segments along the member length. Each length sub-segment is additionally divided into sub-element through the beam cross section to define the cross section shape. The beam element is treated as superelement whose stiffness is defined by stiffnesses of its sub-elements (Figure 2). While the intermediate nodes along the members are reduced for stiffness, the deflected shape of element is represented by all sub-segments [14].

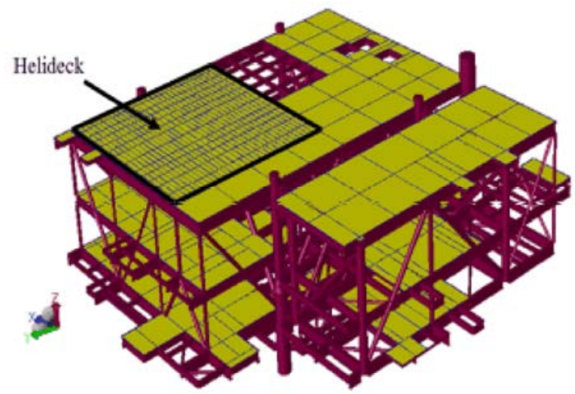

Fig. 3. Helideck on Topside of the Jacket [20].

For any stiffness iteration, each sub-element is checked for plasticity using a Von Mises stress surface. When the stresses in sub-element exceed the material elastic limit, the sub-element is considered plastic, thus allowing for gradual plastification of the beam cross section. So when all sub-element of a particular sub-segment become plastic, a temporary hinge is formed at that sub-segment and with load increasing the collapse will occur for member or structure. This study has used the incremental nonlinear analysis (SACS, full plastic collapse module) for determination of helidecks structural response at emergency landing condition. The “plastic Collapse” mode of assessment offers an improved design concept over linear “elastic” theory for the analysis/re-analysis of structures. The basic concept of the plastic collapse analysis is as follows [14]:

The load is applied to structure incrementally. The nodal displacement and element forces are calculated for each load step and the stiffness matrix is updated. When the stress in a member reaches the yield stress plasticity is introduced. The introduction of plasticity reduces the stiffness of structure and additional loads due to subsequent load increment will be redistributed to adjacent members to the members that have gone plastic. This phenomenon will continue until the structure as a whole will collapse or is “Pushed Over”.

Case Study

Specification of Model: This section introduces the topside of an offshore jacket which already has been modeled in SACS by Worley Parsons and Iranian Offshore Engineering and Construction companies for performing in Persian Gulf (Figure 3). This jacket has been designed by static analysis, 9 positions of its helideck have been selected for this study on the top side. The Topsides are made with two separate structures;

Table 1: Specification of stringers.

Profile	Flange Width	Flange Thickness	Total Depth	Web Thickness
WG21	35 cm	3 cm	100 cm	1 cm
WG22	35 cm	2.5 cm	100 cm	1 cm

The Main module is a truss-framed structure which consists of four decks; Upper deck is at elevation +26.00 meter. The helideck is on the platform north-west corner of the upper deck of jacket. The helideck stringers (IPE240) run platform north south supported on the platform east-west primary beams (W G21 and W G22), Table 1 has described the specification of the Primary beams. Helidecks dimension is 20×18.7 m^2 with the plates by 10 mm thickness [20].

Specification of Expected Helicopter and Loading: The helideck is designed to accommodate the BELL B412 SP helicopter class type (appendix 1) with a gross weight (MTOW) of 5398 Kg (11900 lbs). Three conditions were considered for this deck in design procedure as follows;

- Helicopter at Rest.
- Heavy Landing.
- Emergency Landing.

The helicopter load is distributed into 4 point loads (2 fore gears and 2 aft gears). The distance between fore and aft gears is 2.4m as per API RP-2L [12]. The percentage of load taken by fore and aft gears is 20% and 80% respectively as per API RP-2L [12].

The helideck primary and secondary beams are designed to withstand the emergency landing of a fully loaded design helicopter. The impact load is 2.5 × SRF × maximum take-off weight (MTOW) of the design helicopter. SRF is the structural response factor which is 1.3 as per CAP 437 [13]. The helicopter impact load is (17559kg) 172.25kN. The helicopter was assumed to land in any orientation, at any position on the helideck. In conjunction with the above landing loads, a lateral load of 2701 kg (26.5kN) which is equal to half of the helicopter maximum take-off weight had been considered and assumed to act in the same direction as the wind loading. So the combination of vertical and lateral load of above emergency landing loads will consider in this study for the SACS input data.

Emergency Landing Load Positions: This study considers 9 positions for emergency landing which have shown in the figure 4. These positions are located at

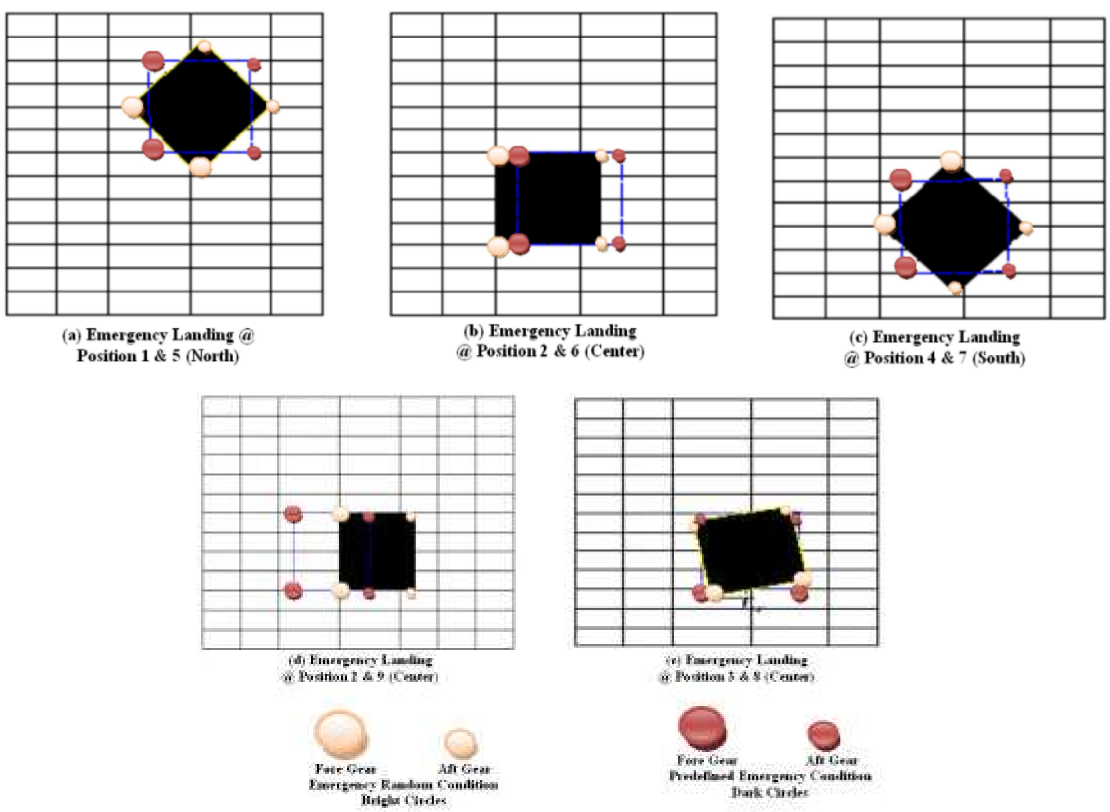

Fig. 4: Emergency Landing Positions on the Helideck.

the north, center and south of helideck. 4 types of them predefined by designers which they have signed by dash lines and dark circles (position 1, 2, 3 and 4) and the remaining five positions (black hachured area and bright circles) have chosen in order to assess the random conditions of helicopter axis rotation (Fig 4.a, c and e) and review the helideck response due to landing on the stringers joints (Fig. 4.b and d) (5, 6, 7, 8 and 9 positions). The helicopter axis was assumed that has been rotated 45° in positions 5 and 7 (Fig. 4.a and c) and also has been rotated 11.25° in position 8.

Joints and Members Monitoring: In order to monitor the plastic behavior of helidecks, all the members and joints around of these 9 positions have been defined for SACS collapse data generator.

Collapse Primary Data: Nonlinear data has been coded by SACS data generator for pushover analysis of emergency landing load. These data includes;

- Maximum Iteration per Load increment: 80
- Number of Member Segment: 10
- Maximum Number of Member Iteration: 40
- Strain Hardening Ratio: 0.002
- Plastic Ratio: 0.5
- Number of Load Increment: 350
- Start and Ending Load Factor: 0~3.5

RESULTS

Members Ultimate Strength at Position 1 and 5: Results of the Von Mesis Stress for the stringers which they have been under the fore gears load is shown in the figure 5 and 6. Considering the helicopter axis rotation at position 5, nonlinear behavior of the member has started after load factor 2, but in the position 1, this behavior has started before load factor 2. The trend of the load factor remained constant after load factor 300 N/mm^2 at pos'n 5, while this trend increased gradually in pos'n 1untill collapse step.

Pushover Curve for Position 1 and 5 (North Section): The maximum nodal displacement value in these positions (1 and 5) at collapse step is 25 mm which has occurred in adjacent of the fore landing gears at position 5 (nod H247). Pushover curve has been created for joint number H247 which it is the interface of both landing positions (Figure 7).

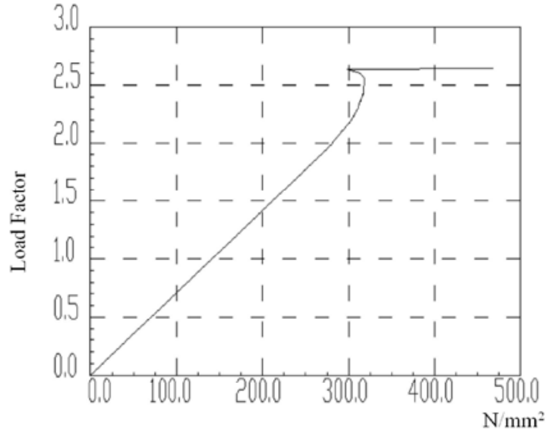

Fig. 5: Von Mesis Curve for the members under fore gears load, E. Landing @ position 5

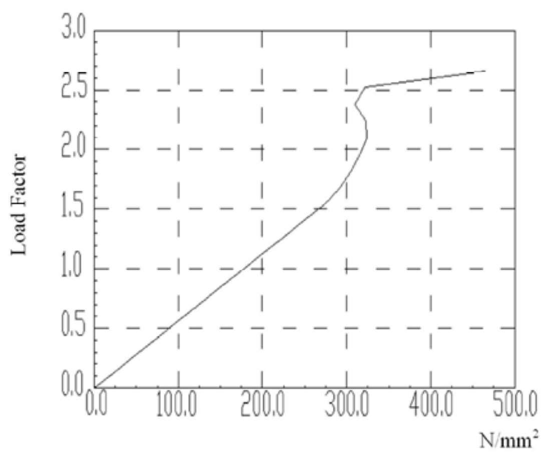

Fig. 6: Von Mesis Curve for the members under fore gears load, E. Landing @ position 1

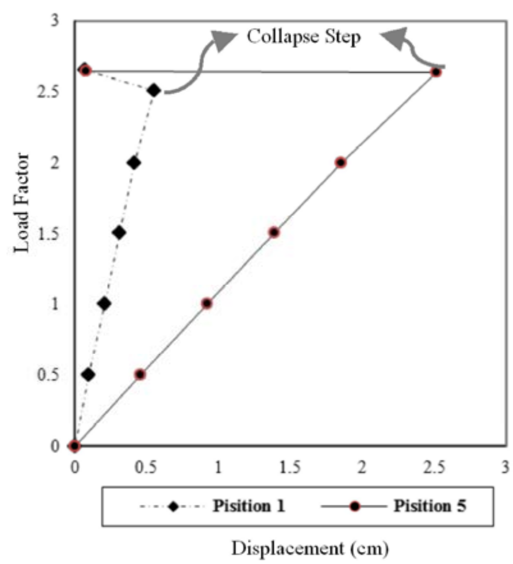

Fig. 7. Pushover Curve for joint Number H247

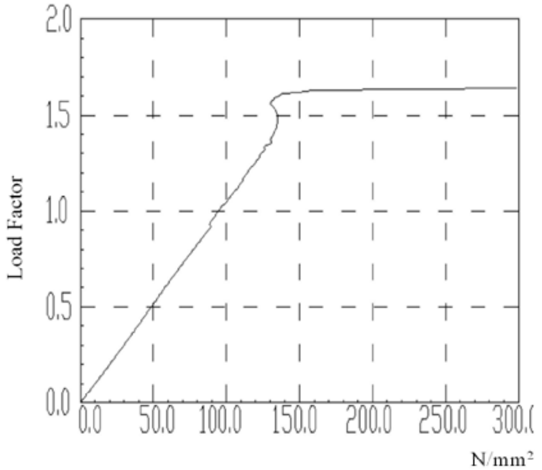

Fig. 8: Von Mesis Curve for the members under fore gears load, E. Landing @ position 8

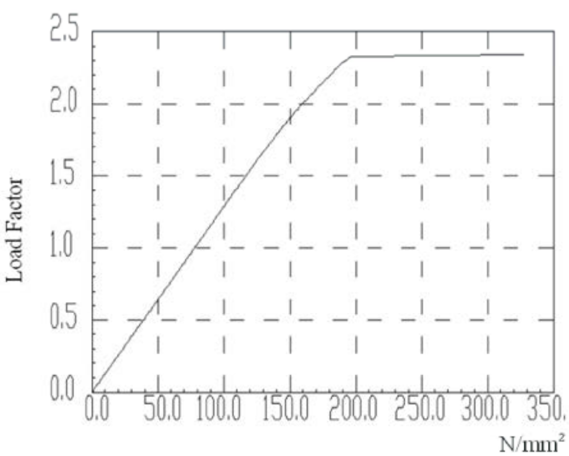

Fig. 9: Von Mesis Curve for the members under fore gears load, E. Landing @ position 2

This curve is describing the total displacements at position 5 verses load factor, is almost 5 times more than position 1 and also the effect of helicopter axis rotation on nodal behavior.

Members Ultimate Strength at Position 2, 6 and 8 (Center Section): Von Mesis Stresses for the stringers which they have been under the fore gears load are shown in figure 8 and 9 for positions 2 and 8. Considering the differences between these positions, nonlinear behavior of the members at position 8 has started before load factor 1.5 and collapse mechanism has formed at load factor 1.64 (Figure 8), while this behavior has started after load factor 2 at positions 2 and collapse mechanism has formed at load factor 2.34 (Figure 9).

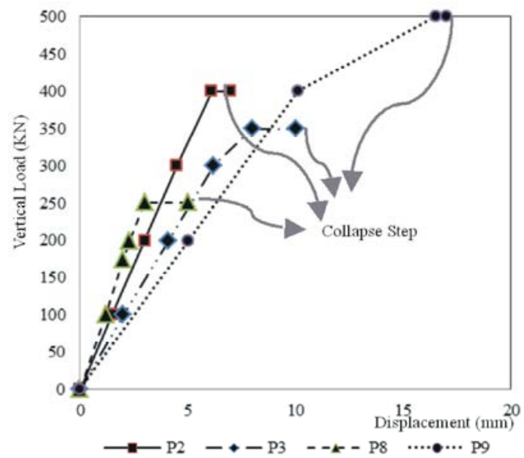

Fig. 10: Pushover Curve for joint Number H247

In both cases the load factor remained constant until collapse step. For the position 6 it should be noted whereas the landing load has applied on the main stringers joint (WG21), load factor has increased up to 10.

Pushover Curve for Position 2, 3, 8 and 9 (Center Section): In order to assess and compare the nodal behavior under positions 2, 3, 8 and 9, pushover curve has been created for joint number H259 which is the interface of maximum total displacement at all of mentioned positions. It should be noted that curves are describing the nodal vertical displacement verses vertical loads. These curves are describing random positions reduces the nodal strength under emergency landing, Position 8 which has a random condition with smallest axis rotation could resistant against less load. Considering P2, P3 and P8 in figure 10, helicopter axis rotation could reduce the structural resistance against the emergency landing; also joints (Fig. 10-P9) could carry out appropriate strength in compare with the stringers.

Members Ultimate Strength at Position 4 and 7: The result of the Von Mesis Stress for the stringers that they have been under the fore gears load is shown in the figure 11 and 12. Considering the helicopter axis rotation at pos'n 7, nonlinear behavior of the member has started after load factor 2, but in pos'n 4, this behavior has started before load factor 2. The increasing trend of stresses at pos'n 4 continues until load factor 2.3 and then with further increasing of load factor the ultimate strength of the member has reduced due to full plastic collapse mechanism, while at pos'n 7 the load factor remained constant until collapse step at load factor 3.00.

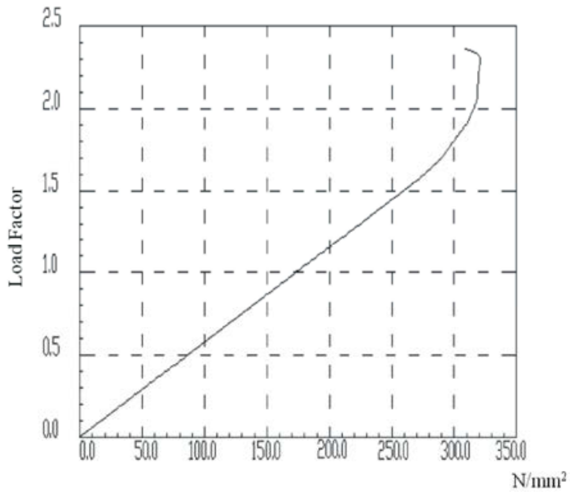

Fig. 11: Von Mesis Curve for the members under fore gears load, E. Landing @ position 4

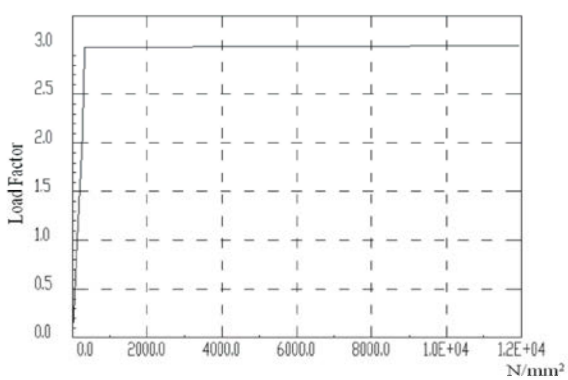

Fig. 12: Von Mesis Curve for the members under fore gears load, E. Landing @ position 7

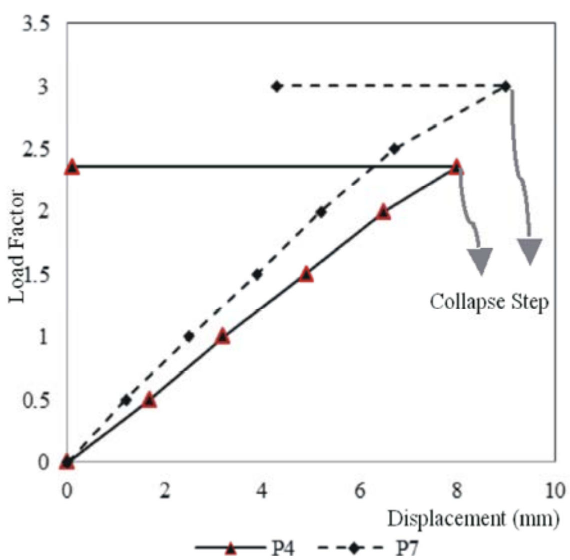

Fig. 13: Pushover Curve for joint Number H266

Pushover Curve for Position 4 and 7: In these positions, the maximum nodal displacement is 9 mm which also occurred in adjacent of the fore landing gears at pos'n 7. Pushover curve has been created for joint number H266 which is the interface of both landing positions (Figure 13). Considering the nodal response at both positions, permanent deformation has occurred at pos'n 7 while transient deformation is performing at pos'n 4.

DISCUSSION AND CONCLUSION

- Helicopter axis rotation at emergency landing conditions has significant effect to reduce the structural and member's strength, for 0° angle (Pos'n 3) collapse mechanism has formed at load factor 2.03 while for 11.25° angle (pos'n 8) collapse has formed at load factor 1.64.
- According to the Newton law ($F=m.a$) when the load factor is 1.64 (at position 8), which is the lowest and considering the helicopter weight, inconvenience acceleration of machine is 5.33 m/s^2.
- Positions 2 and 3 are performing as emergency landing on parallel and series stringers at center of the helideck, since collapse has formed in Series type at load factor 2.03 and also has formed in parallel type at load factor 2.34; parallel stringers has acceptable behavior and appropriate strength in comparing with series type.
- If the emergency landing occurred on the joints (positions 6 and 9), the structural response will be more satisfy in comparing with landing on stringers (position 2, 3 and 8).

REFERENCES

1. HSE, 2000. Helicopter Safety offshore, offshore technology report, 2000/089.
2. Vaghefi Mohammad and Bagheri Hassan, 2010. Evaluation of Software Such SACS, Ansys and Abaqus in nonlinear Analysis of offshore Structures, Journal of Marine Science and Technology (in Persian).
3. Clarkson, J., 1960. Tests on flat plate grillages under concentrated loads, Trans. RINA, pp: 129-142.
4. Harding, M.J.H., 1963. A method of measuring helicopter landing loads, British European Airways, Helicopter Note No 140, October 1963.

5. Jackson, R. and P.A. Frieze, 1981. Design of deck structures under wheel loads, Trans RINA, 123: 119-144.
6. Garron, S., 1990. Helicopter induced deck loads, presented to SNAME's Eastern Canadian Section, December 1990.
7. Qiang Chena, Zhifu Gua, Tianfeng Suna and San Songb, 2005. Wind environment over the Helideck of an offshore platform.
8. Shojaee, S. and S.M. Asghari, 2009. Concepts of linear and non linear analysis, (in Persian).
9. Sivaselvan, M.V. and A.M. Reinhorn, 2003. University of Buffalo, Nonlinear Structural Analysis towards Collapse Simulation-a Dynamical Systems Approach, March 30, 2003.
10. Sivaselvan, M.V. and A.M. Reinhorn, 2003. University of Buffalo, Nonlinear Structural Analysis towards Collapse Simulation-a Dynamical Systems Approach, March 30, 2003.
11. Sivaselvan, M.V. and A.M. Reinhorn, 2003. University of Buffalo, Nonlinear Structural Analysis towards Collapse Simulation-a Dynamical Systems Approach, March 30, 2003.
12. API-RP2A American Petrolum Institute
13. API-RP2L, American Petrolum Institute Recommended Practice for Planning, Designing and Constructing Heliports for Fixed Offshore Platforms.
14. CAP, 2008. 437 Offshore Helicopter Landing Areas-Guidance on Standards 2008.
15. SACS, 2005. Version 5.2 Documentation. User's Manual.
16. CAA, PAPER 2008/03 Helideck Design Considerations-Environmental Effects.
17. Helideck Structural Requirements, 2001. Prepared by PAFA Consulting Engineers for the Health and Safety Executive.
18. DNV-OS-E401, 2009. Offshore Standard DET NORSKE VERITAS Helicopter Decks October 2009.
19. Advisory Circular, 2004. 150/5390-2B, Heliport Design Guide, Sep 2004.
20. ISO 19901-3, 2007. Petroleum and Natural Gas Industries-Specific Requirements for Offshore Structures, Part 3: Topsides Structure expected to be published in 2007.
21. Wellhead Platform, 2009. SPD 12B Helideck Documentation
22. Bell Helicopter, 2010. Bell 412, Product Specification.