Performance of Circular Opening in Beam Web Connections

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Abstract: Fragile behavior in the area around the connections which is tangent on beam to column and also incidence of brittle cracks and failures in this area, in the event of severe ground shaking, are the main problems and disadvantages that have negative effect on the performance of steel bending frames and would have restrictions effect on the of the frame's plasticity behavior. To solve the problem of bending the frame, two methods have been proposed. In the first method, the connection will be strengthened so that has enough resistance and sufficient strength to prevent cracks and failures to non-elastic deformation of the frame in the inner part of beams be answered. In the second method, instead of strengthen the connection area; the middle part of beam in a certain distance from the terminal connection would weaken intently. So, this weakened section act as a fuse and cause attracting and transmitting place of occurrence of the most transmission of frame shape request to a new far area and also would prevent cracking of the connection and its associated elements. In this paper, we investigated the transformations of frames against lateral force by weakening of the circular hole in a far away area.

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1- Introduction:

Generally, designation in steel structures was based on high plasticity of steel and capability of high transformations and significant energy loss in earthquake by steel. After Northridge earthquake in 1994, initial observations showed the suitability of designation trend in the steel structure, but by doing more accurate tests and also symptoms after the earthquake, engineers found that the steel structures have not shown the necessary flexibility against earthquake. In fact, brittle behavior of welded joints in frame structures caused this event and in many cases, before beams' failure, these beams have experienced fragile failure in weld joints of beams to the columns (Mahin, 1998). The main reason of this behavior is in thermal stresses caused by welding, stress concentration and so on.

Qingshan et al. (2009) showed that openness in beams at a distance far enough from junction would improve seismic behavior of bending frames; On the other hand, this opening does not affect the structural stiffness and the final shift structures increases and finally a large amount of energy from earthquake would loses due to deformation of local shapes in the area. Investigations showed that Failure mechanisms in these beams similar with Vierendeel mechanism were been reduced in place and can avoid from weld brittle failure at the junction. Qingshan et al. (2009) calculated plastic joint's place around the holes in 0.45R distance which showed in following:

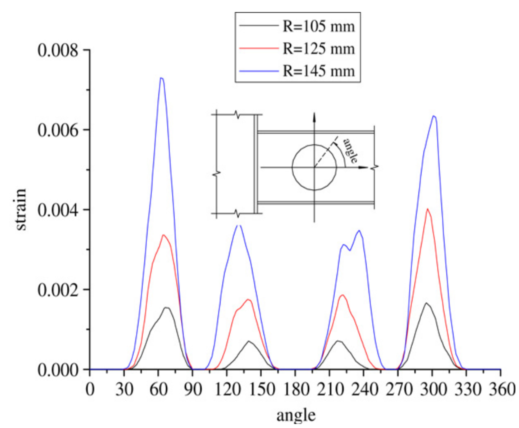

Fig (1-1): distribution of effective plastic strain

Chung et al. (2001) have found that openness in beam would reduce the ultimate beams' loading capacity, but in beams with large openings and a third location opened in the initial and final stone can be used regardless of the loading by studying on two-head beam. Besides, they represent an exponential relation for shear and bending beam reactions with openness by examining the finite element model of a two-head beam.

$$\left(\frac{V_{sd}}{V_{0,Rd}}\right)^{2.5} + \left(\frac{M_{sd}}{M_{0,Rd}}\right)^{2.5} \leq 1$$

Which,

V_{sd} and M_{sd}: Shear and anchor from structure analysis in entry of hole

M_{0Rd}, V_{0Rd} : shear and bending capacity of beam in entry of hole

Liu and Chung (2003) found that all shapes except circle, will form plastic joints in two ends of upper and under T form and also, bearing capacity in different shapes, with constant altitude and longitude, is identical.

Lawson et al. (2006) found that in composite beams which have continuous holes, if the longitude of beam being large enough, effects of second anchors ($P.\Delta$) should be seen in Vierendeel mechanism, so to undergo these effects, they had considered reduction coefficient (K_L).

$$K_L = 1 - \frac{l_{eff}}{25D_t}$$

In abovementioned equation:
L_{eff}= Effective opening length
D_t = depth of upper form T
In this paper, different diameters were considered for circle hole and also different location for this hole was also considered and their effects on the behavior of these joints was evaluated.

2- Stress-strain graphs of elastic state – perfectly plastic

In this paper, steel with yield stress 240 N//mm^2 were used and elastic state – perfectly plastic were considered based on below figure, If it's need to be manually verified by analyzing the results of the review.

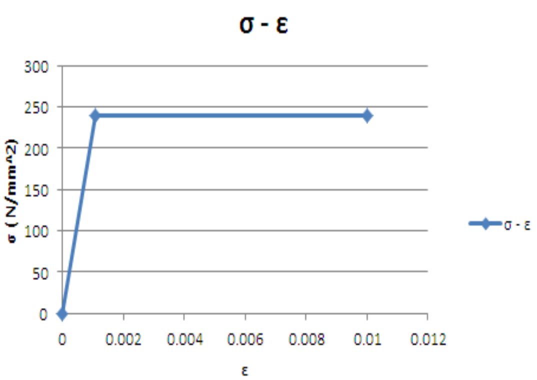

Fig (1-2): Stress-strain graphs of elastic state – perfectly plastic

3- The necessity of using stiffener

According to exist a hole in the beams of open connections (RWS), it's possible to occur local buckling of the beams in place. Thus, on a reduced need for beam, necessity of using stiffener was evaluated. Beam of W36x15 were modeled in three state of without loss of beginning of beam, with loss of beginning of beam and also with a hard life in limit element software. Dimensions of the holes intended for the hardening of 150x10mm and examples of the model are shown below.

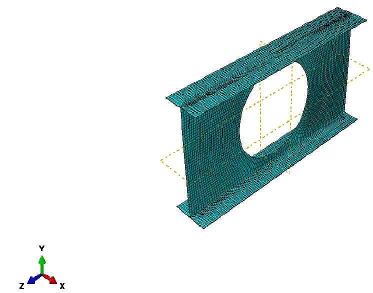

Figure (1-3): beam without loss in its strength

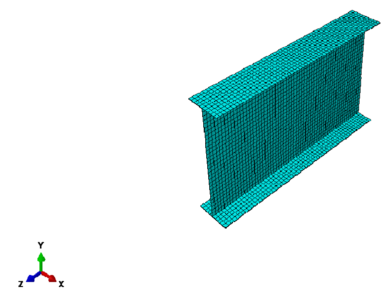

Figure (2-3): beam with loss in its strength without stiffener

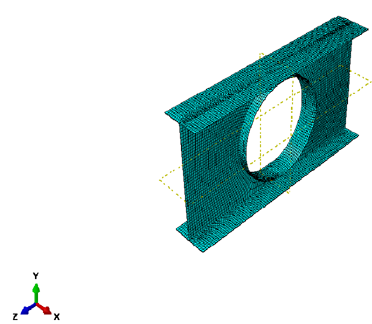

Figure (3-3): beam with loss in its strength without stiffener

After carried on analyzing on three modeled beam of V-Δ and M-θ curves were obtained as follows:
Where:
V: shear force exerted on the end of beam
M: bending moment on the end of beam
Δ: terminal displacement in beam
θ: rotation of the end of beam

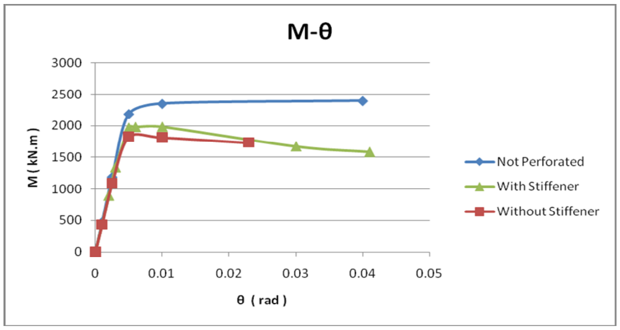

Figure (3-4): M-θ curve on modeled beam

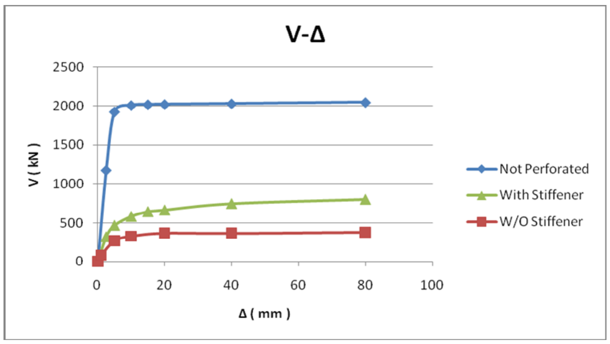

Figure (3-5): V-Δ curve on modeled beam

As is clear from the above graphs, the overall behavior of holed beam would improved and the hole will prevent local buckling, the hardware dimensions must be chosen as beam hole with the original shooting bullets that are not as strong as in the above diagrams.

Curve associated with holed beam stiffeners, the original beams located in the following diagram and the dimensions selected is appropriate for the stiffener.

4 - Modeling stiffeners beams fell with a circular hole

In this study, 5 beams with different holes dimensions according to the following table in addition to no holes beams were investigated.

Table (4-1): Profile of a considered circular hole

Beams names	Full stiffener s	D55%	D60%	D65%	D75%	D85 %
Perforated Percentag e (%)	0	55	60	65	75	85
Hole diameter (mm)	0	502/ 9	548/ 6	594/ 4	685/ 8	778

Two abovementioned beams were investigated in two limit condition. In the first case, the center of all holes are placed in 0.6d of considered column and in second case, the center of all holes are placed in d of considered column. It's noteworthy that since a hole with 0.85 diameters has a radius equal 0.425d, if the center of circle placed in 0.5d, from side of the hole was very close to the end of the connection and realizing that plastic strain around the holes are located or in the connection was not possible, because the center of the column in the first mode is selected equal to 0.6d. in order to realizing the place of holes, before "d" letter of each beam, terms of 1.2 or 2 were used which show 0.6d and d distance from side of column.

5- Review the results of the analysis

All modeled beams were received pure shear force (V) in the end of its position and also received a pure bending moment (M)) in the end of its position, and also Shear force diagrams - shift and bending moment - the time for these beams are obtained.

All results from analysis of these beams under pure shear force, shows that these beams have a unique behavior and all plastic strains located around the hole and the desired transformation of the following figures are in this range and so, plasticity of these beams could depreciate energy of earthquake.

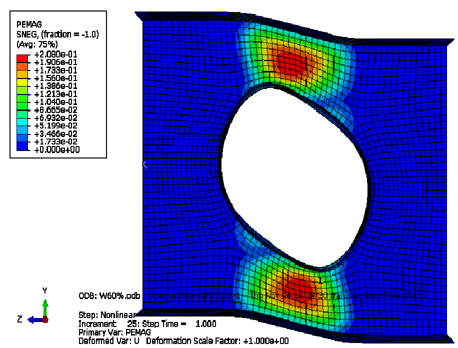

Fig (5-1): Distribution of plastic strains in 1.2d55% beam

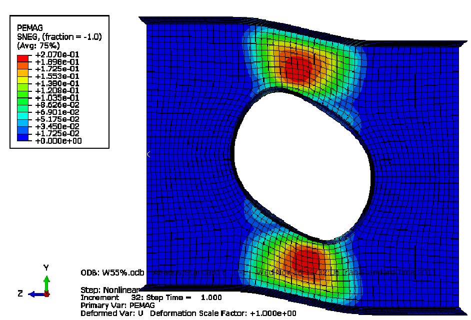

Fig (5-2): Distribution of plastic strains in 1.2d60% beam

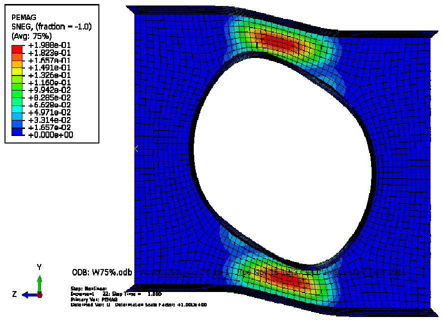

Fig (5-3): Distribution of plastic strains in 1.2d65% beam

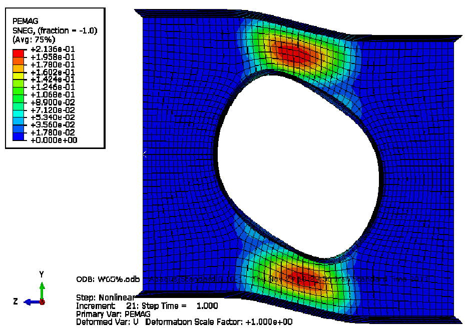

Fig (5-4): Distribution of plastic strains in 1.2d75% beam

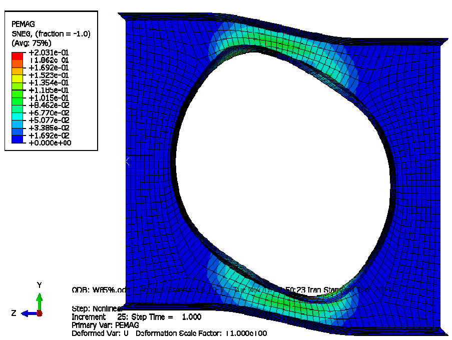

Fig (5-5): Distribution of plastic strains in 1.2d85% beam

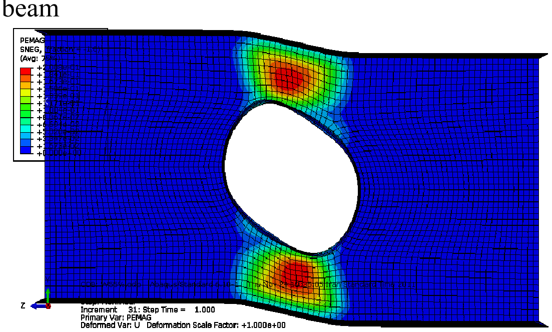

Fig (5-6): Distribution of plastic strains in 2d55% beam

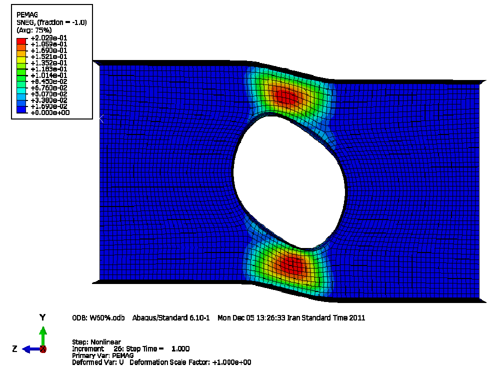

Fig (5-7): Distribution of plastic strains in 2d60% beam

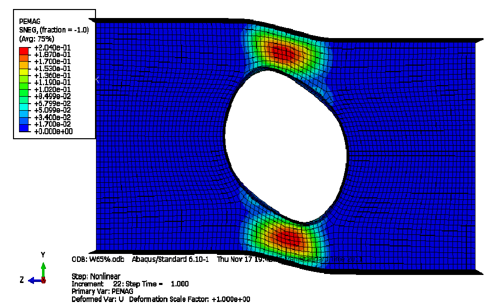

Fig (5-8): Distribution of plastic strains in 2d65% beam

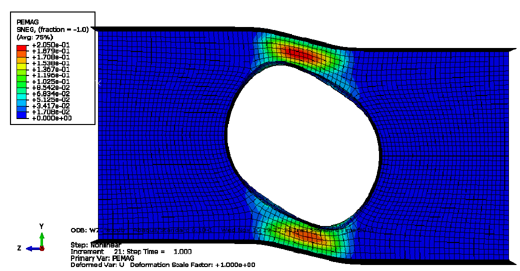

Fig (5-9): Distribution of plastic strains in 2d75% beam

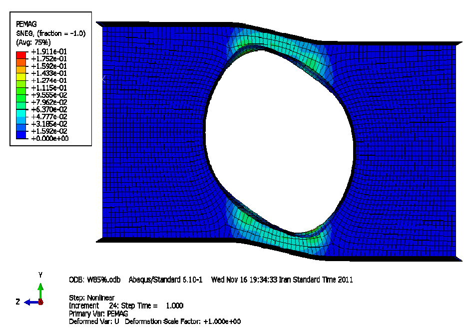

Fig (5-10): Distribution of plastic strains in 2d85% beam

Diagrams of V-Δ which are related to the considered beams were shown in bellow figures. Endpoints of these graphs can be selected based on three criteria. The first criteria is plastic strain reaches the maximum and make rupture strain of steel investigated in this study, the value of 0.2 is considered, the second criterion, if not more than 20% drop in resistance on the charts this fall, And finally, the third criterion is dominant when add the amount of plastic strain Δ-hole connection and the connection to be plastic.

As its obvious in abovementioned figures, these beams have good plasticity under pure shear force and would intended to meet seismic requirements, but as its obvious in following figures, the beams under pure bending force if they are not appropriate behavior and thus do not meet seismic requirements. This can cause the formation mechanism is not understood Vierendeel in this hole under bending moment. As long as these beams are under pure shear force, because of existing Vierendeel mechanism, it has high plasticity and plastic deformation and strain around the hole hold but in pure bending mode due to lack of mechanism Vierendeel this strain had accumulated in the column and do not meet seismic requirements. After exact investigation on beams in this research, we saw that in %55 and %60 of beams span length was evaluated for both pre-formed plastic strains around the hole are formed at the junction and in other beams, after making the first plastic strains around the hole, further strain can be located at the junction.

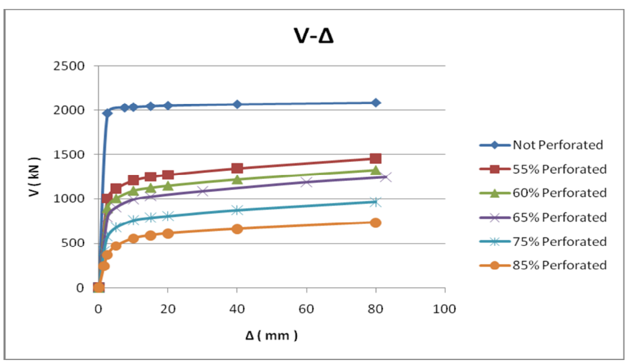

Fig (5-11): V-Δ chart of beams with 1.2d length

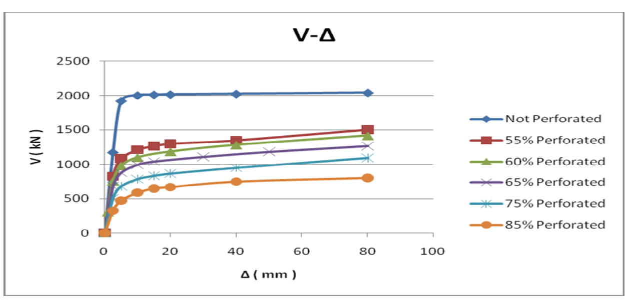

Fig (5-12): V-Δ chart of beams with 2d length

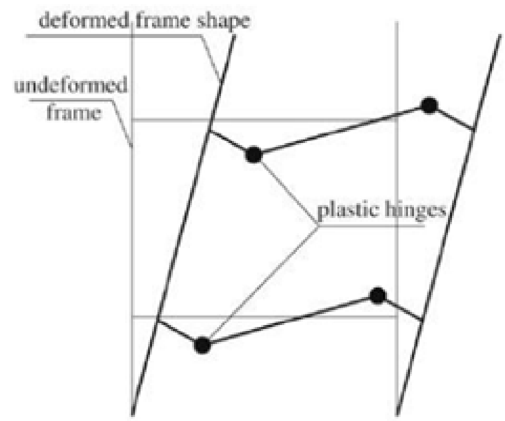

Figure (5-13): The mechanism for the proper behavior of connections RWS

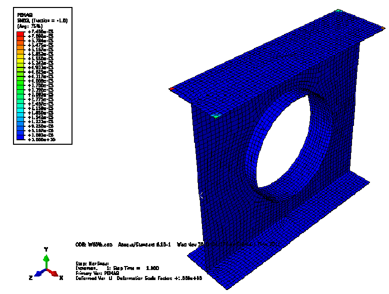

Fig (5-14): Distribution of plastic strains in 1.2d55% beam

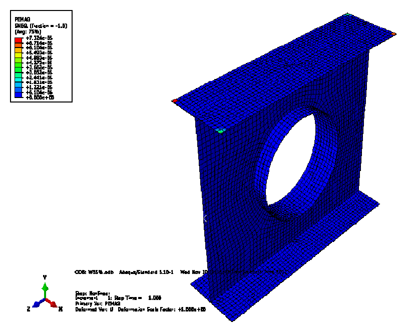

Fig (5-15): Distribution of plastic strains in 1.2d60% beam

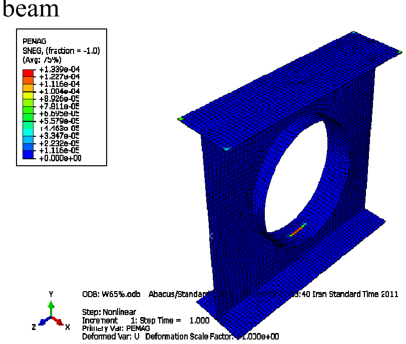

Fig (5-16): Distribution of plastic strains in 1.2d65% beam

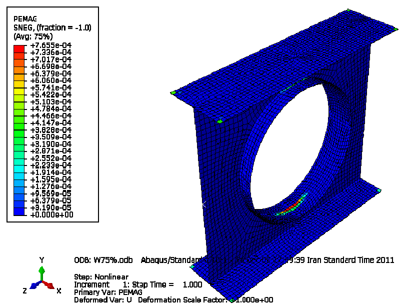

Fig (5-17): Distribution of plastic strains in 1.2d75% beam

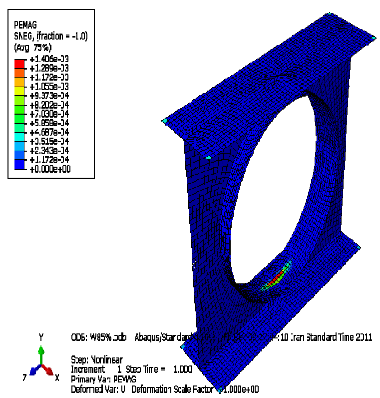

Fig (5-18): Distribution of plastic strains in 1.2d85% beam

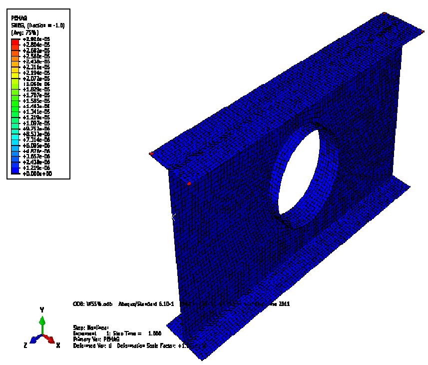

Fig (5-19): Distribution of plastic strains in 2d55% beam

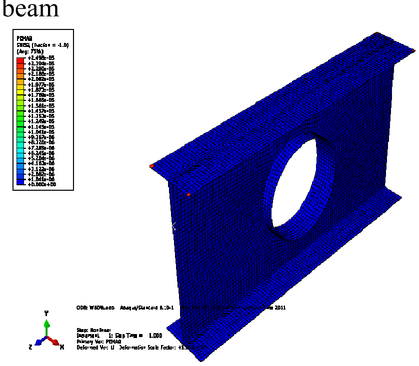

Fig (5-20): Distribution of plastic strains in 2d60% beam

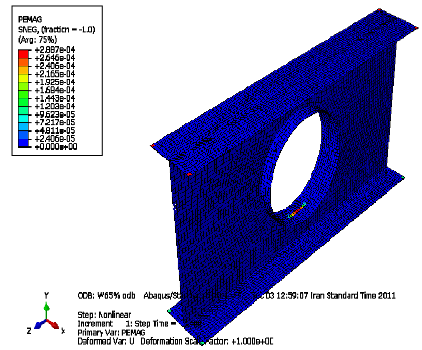

Fig (5-21): Distribution of plastic strains in 2d65% beam

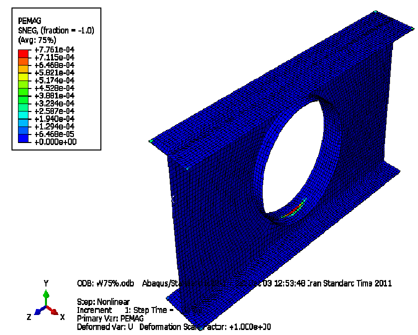

Fig (5-22): Distribution of plastic strains in 2d75% beam

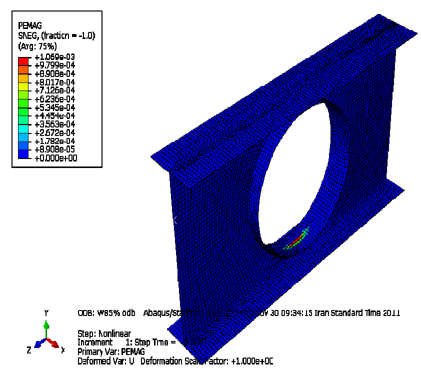

Fig (5-23): Distribution of plastic strains in 2d85% beam

It's note worthy that in 2d %85 beam, because of the relative strain in the software are displayed with different colors, the connection is shown at zero strain. While, if you choose to connect points on the graph in terms of plastic strain analysis of time to draw the figure below, it can be seen in the column and connect this arrow point to the plastic strains occurred and this connection is also not acceptable.

By designing exact charts of M-θ for abovementioned beams, bellow figures would obtain. Based on above figures, we know that %55 and %60 beams do not have appropriate behavior and the maximum allowable strain imposed on the connection will cause the plastic strain, and for 1.2d and 2d beams are 0.002 and 0.0035 respectively. As it's obvious in following figures, approximately beams figures didn't get out of line graphs of the first plastic strains arise in the connection.

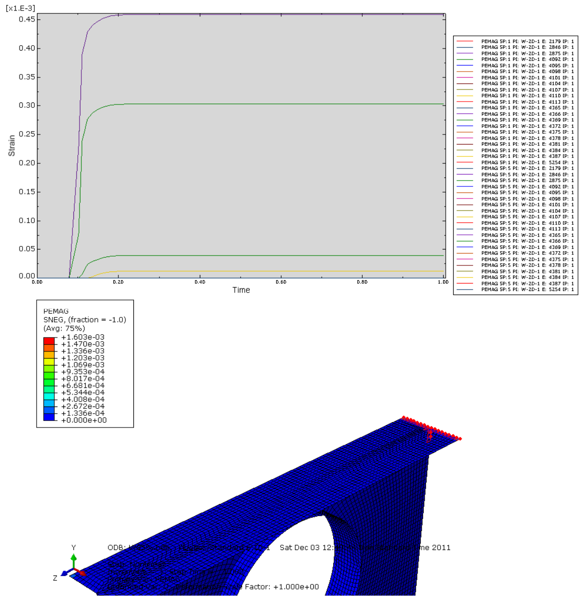

Fig (5-24): Diagram of plastic strain based on time of analysis for determined points.

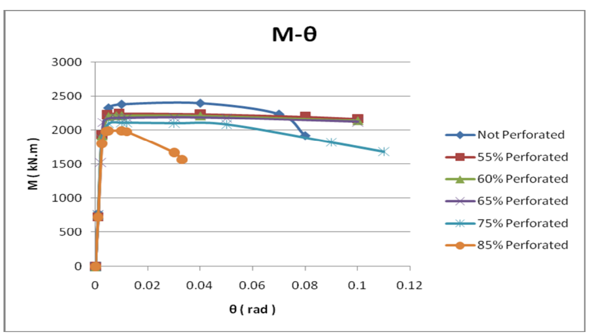

Fig (5-25): M-θ chart of beams with 1.2d length

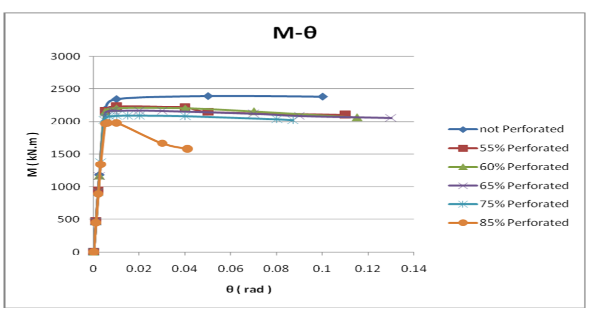

Fig (5-26): M-θ chart of beams with 2d length

6- Conclusion:

In this paper, behavior of connection with open end circle was investigated. By modeling various diameters of holes, the impact of this parameter on connections were studied and also the location of these holes rather than side of the columns were investigated and its impacts was represented.

Effect of stiffeners in this article showed that in the absence of hard at the puncture site due to local buckling phenomenon of cargo, the connection dropped and hard choices with appropriate dimensions can have significant impact in improving the behavior of these connections.

RWS fitting with a circular hole under shear loads have very good behavior and earthquake energy and good will depreciate and plastic strains to come into focus around the hole.

Open end connections were in circle shape the bending moment is not appropriate behavior and the formation mechanism of Vierendeel plastic strains around the hole to move the connection and hypothesis of "weak beam-strong column" would rejected.

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