# THE CONTINUITY PLATE EFFECT ON PANEL ZONE DUCTILITY WITH UNEQUAL BEAMS HEIGHT ON BOTH SIDES OF COLUMN IN SMRF

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**ABSTRACT**:

Panel zone has a crucial role in transferring the lateral load to other elements in Steel Moment Resistant Frames. To some extent, this element through its ductile behavior can greatly increase the overall ductility of SMRF. Taking benefit of this ductile behavior in panel zone design, one can highly increase the performance of SMRF. Continuity plate has a fundamental effect in ductile behavior of panel zone. The effect of continuity plate on panel zone behavior has been investigated under monotonic loading in the past. The main aim of this paper is an analytical study on panel zone ductility due to presence and absence of continuity plate and type of continuity plate arrangement. The research method is based on verifying the analytical model, built in ANSYS Finite Element Software, with experimental model in laboratory test. This verification permits us to make different models with variety of geometry parameters of panel zone (i.e. depth of beams and thickness of column flange, presence & absence of continuity plate and arrangement style of continuity plate).Then the obtained ductility ratio from analysis is used for consideration of panel zone ductility of FEMA356 and comparison of panel zone ductility due to presence and absence of continuity plate and type of arrangement. The obtained result that is derived from this research shows that the amount of panel zone ductility estimation in FEMA356 in most of geometry cases is non conservative. In most of geometry conditions, presence of continuity plate increase panel zone ductility. Presence of inclined continuity plate that is located in front of bottom flanges of unequal beams sizes (with inequality in height of beams) in which height of shallower beam is equal or less than half of the height of deeper beam, according to partial ductility of panel zone is more effective than the horizontal continuity plate, whereas presence of two straight continuity plate that is located in front of bottom flanges of unequal beams sizes(with inequality in height of beams) in which height of shallower beam is equal or more than half of the height of deeper beam, panel zone has more ductile behavior than the inclined continuity plate.

**KEYWORDS: Panel Zone, Continuity Plate, Partial Ductility**

## 1. INTRODUCTION

There have done little research on the basis of panel zone ductility and effect of continuity plate on its behavior since now but the main aim of this paper is considering panel zone ductility according to the backbone curve which is drawn on histertic curve in beams with unequal height on both sides of column in SMRF. In this paper two special matters are considered:1-in the past research [6] there have bean few tasks on the basis of panel zone ductility in beams with unequal height and effects of continuity plates arrangement .2-in the past, due to limitation in lateral displacement and limitation and requirements of axial loading apparatus in the experimental model, in plane lateral displacement was restrained and possibility of in plane lateral displacement of column tip was deleted. On account of the fact that panel zone is more challengeable in SMRF and there is feasibility of lateral displacement in real behavior of SMRF; moreover, there is possibility of movement in column tip ;therefore, column tip must be released in modeling so that the behavior of panel zone can be estimated accurately. This can consider the effect of overall buckling of column on panel zone. It is worth mentioning that the true behavior in beam column assembly is between complete rigidity and complete freedom of column tip which is derived from one connection of SMRF and this flexibility is related to relative stiffness of connected elements of subassemblagement.

But considering and substitution of this stiffness is a very complex and difficult task ,therefore; the column tip is

released to consider the flexibility of panel zone in that it is conservative and results in lower limit of amount of ductility ;furthermore this style of modeling is close to real behavior[8],[10].defined specimens in this paper are modeled according to verification of experimental test; moreover, it was tried to define geometry of element in definite tolerance and hypothesis of same performance between experimental and analytical specimens. In this article three main parameters in panel zone are studied:
1- relative change of height of beams .
2- change of thickness of column flanges.
3-types of arrangement of continuity plate (straight and inclined) and basically importance of presence of continuity plate are studied even though it is not required according to IBC2000.

## 2. DESCRIPTION OF MODELING

Considering issues mentioned on behavior of panel zone, the need for carrying out some tests became necessary for Popve[9] and Colleagues. Therefore, some specimens were made for these tests. As noted in real scale the proto type beam column assemblies were very large and in most cases involved 36 inch deep members. Loading requirement on such assemblies to induce significant deformation or failure would have been beyond the capacity of the available equipment. To reduce this loading requirement the members were made half-size. As rolled sections were not always available to meet the half scale factor chosen, they were fabricated from rolled plate cut to the appropriate dimensions. Each specimen consists of single column 9ft-6inch long with cantilever beams on each side of the column at mid-height .the column length was chosen so the inflection points duo to applied moment at the middle of column would produce inflection points corresponding to mid-stories in the prototype. In view of the fact that specimen 8 has stable hystertic loops and slippage of bolts did not happen in shear tab; and failure was not observed in weld tabs, this experimental model selected for verifying of FEM model.

Analytical model was built in finite element program and nonlinear solid properties were utilized. A view of analytical model is shown in Fig4. Weld of column flange to beam is not modeled because failure did not occurred in weld and heated zone. Therefore modeling of weld was avoided as ductile element; likewise, bolts and shear tabs were not modeled since high strength bolt were employed and there was no slippage in bolts and shear tabs.

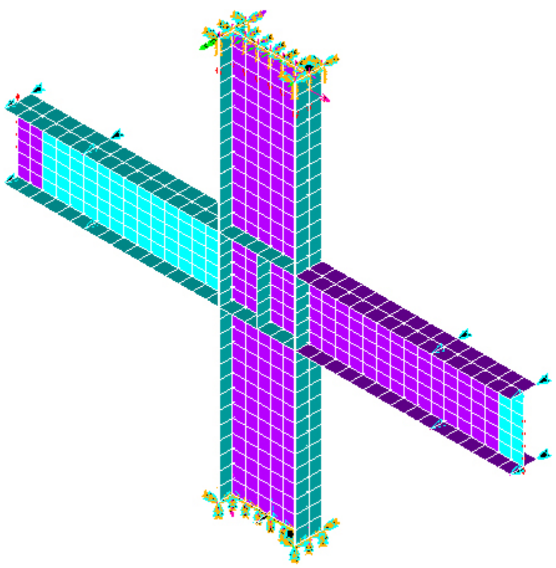

**Figure 1** Analytical model of specimen 8

## 3. VERIFYING OF THE ANALYTICAL MODEL

Isotopic strain hardening in tension and compression in monotonic loading supposed for steel material. Non linear properties through small strain and large displacement formulation are established .there have been possibility in this formulation that it could consider together geometric nonlinearity and material nonlinearity properties. Because of presence of plug welds in real model and their effectiveness in preventing local buckling of doubler plates, local buckling of these plates are not interred into analytical model ,but the rest of buckling cases consist of local buckling of column web and beam flanges and web and continuity plates are considered.
It is emphasized that crack extension issue was not considered, this affair is dependent on potential of cracking through crack extension and crack control criteria, provided that a crack or imperfection are defined in structures[2] [3]; loading of this analytical model is force control; likewise ,experimental model. And also all of loading steps which is employed in experimental model are used in loading of model .and boundary conditions of real model are engaged in modeling similarly.

Finally, considering the above-mentioned issues and using yield laws to justify seismic behavior of analytical model, the seismic behavior curve of this analytical model was drawn. The equality of seismic behavior curves of analytical model and experimental model (hystertic loops) show the approximate correctness of analytical model. According to authors, the reason for approximate adaptation is assumptions governing finite elements based on elasticity and plasticity theories and also approximations assumed for simplifying materials. The average cantilever loads vs. average beam end deflection for analytical and experimental model were similar together (figures 2,3) , in which the maximum cantilever load of analytical model has occurred in – 130 kips and related displacement has occurred in – 2.21 inch when the analysis was interrupted. These amounts are 132 kips and –2.5 inch in experimental model (specimen8), when failure happened in beam flanges and test terminated. In addition, the total applied moment vs. panel shear strain for analytical and experimental models are shown in Figures 4 and 5, in which the maximum total applied moment was 15000 kips-in for both and have occurred in 0.025 radian distortion. The locations and amount of out of plane buckling in experimental and analytical model are approximately the same. The local buckling happened in center of panel zone with amount of 0.5 centimeter out of plane in analytical model which was similar to experimental model. Another local buckling has occurred in continuity plate with amount of 1.27 centimeter out of plane.
In total it could be concluded from above issues that, there is a good adaptation between experimental and analytical models and the analytical model is reliable. Finally it should be noted that if we were attention to peak of hystesis loops we would have seen some difference between peak of hystesis loops of analytical and experimental models .according to the last research [5] the reason of these differences (sharpness of hystersis loops peak) are existence of residual stresses that are not considered in analytical analysis despite of their presence in reality.

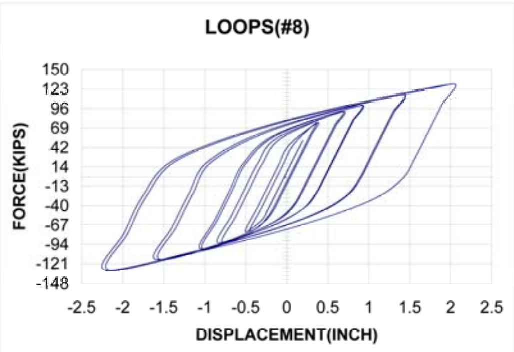


**Figure 2** Curve of total applied load vs. displacement for analytical model

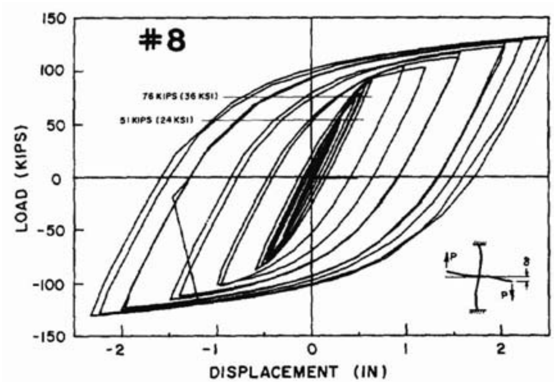


**Figure 3** Curve of total applied load vs. displacement for experimental model

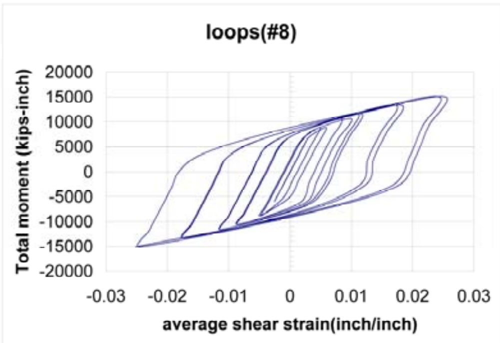


**Figure 4** Curve of total applied Moment vs. shear strain of panel zone for analytical model

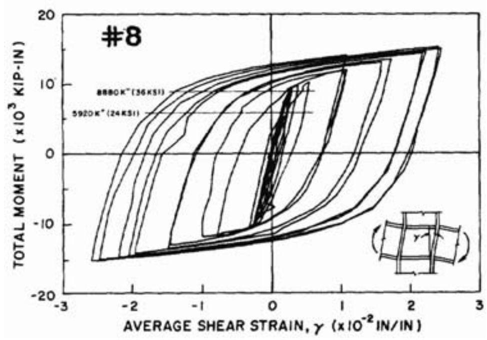


**Figure 5** Curveof total applied Moment vs. shear strain of panel zone for experimental model

Three groups of assembled models have been used in this article, the difference of which is only the thickness of their column flange. Three variable beam heights with definite height differences in both sides of column are specified in each group, and in each definite height difference of beams, the panel zone is designed based on strength approach (IBC2000), in first group both arrangements of continuity plates (straight and inclined) and panel zone without continuity plate despite of the need of continuity plate according to IBC2000 in order to evaluate the effect of continuity plate on panel zone are considered. In second and third group also despite of not demanding continuity plate according to IBC2000, all of notes mentioned in the first group, were also considered in second and third groups. Therefore, 27 samples were made. The important point is the use of shell (Nonlinear) element, which has been used with (4 inch) 10 cm at 10 cm size and these dimensions are almost the same size used for modeling main analytical model in last section. All models were designed based on

AISC-ASD (2001) and design of panel zone on the basis of strength is originated from IBC2000. Meanwhile, specifications of all series and models are included in Tables 3 to 5. Units are in kg and cm.

Table 1 – Specifications of columns built in I shape (with equal flanges)

| | Column 1 | Column 2 | Column 3 |
|---|---|---|---|
| Total height of column web (cm) | 60 | 60 | 60 |
| Thickness of column web (cm) | 1.5 | 1.5 | 1.5 |
| Width of column flange (cm) | 27 | 27 | 27 |
| Thickness of column flange (cm) | 2.5 | 3.5 | 4.5 |

Table 2 – Specifications of beams built in I shape (with equal flanges)

| | beam 1 | beam 2 | beam 3 | beam 4 |
|---|---|---|---|---|
| Total height of beam web (cm) | 50 | 40 | 32 | 25 |
| Thickness of beam web (cm) | 1 | 1 | 1 | 1 |
| Width of beam flange (cm) | 15 | 15 | 15 | 15 |
| Thickness of beam flange (cm) | 2 | 2 | 2 | 2 |

Table 3 – Specifications of Seri 1 model

| Right side beam | Left side beam | Column | |
|---|---|---|---|
| Beam 1 | Beam 2 | Column 1 | model 50 – 40 |
| Beam 1 | Beam 3 | Column 1 | model 50 – 32 |
| Beam 1 | Beam 4 | Column 1 | model50 – 25 |

Table 4 – Specifications of Seri 2 model

| Right side beam | Left side beam | Column | |
|---|---|---|---|
| Beam 1 | Beam 2 | Column 2 | model 50 – 40 |
| Beam 1 | Beam 3 | Column 2 | model 50 – 32 |
| Beam 1 | Beam 4 | Column 2 | model 50 – 25 |

Table 5 – Specifications of Seri 3 model

| Right side beam | Left side beam | Column | |
|---|---|---|---|
| Beam 1 | Beam 2 | Column 3 | model 50 – 40 |
| Beam 1 | Beam 3 | Column 3 | model 50 – 32 |
| Beam 1 | Beam 4 | Column 3 | model 50 – 25 |

Table 6 – Designing thickness of connection zone and continuity plate for Seri 1

| CASE1 | CASE2 | CASE3 | Panel zone ID. | | |
|---|---|---|---|---|---|
| Thickness of continuity plate | | | $t_{pz}$ | $V_{pz}$ | |
| 2 | 2/2 | 200212 | 2/2 | 200212 | model 50 – 40 |
| 2 | 2/1 | 194477 | 2/1 | 194477 | model 50 – 32 |
| 2 | 2/1 | 197292 | 2/1 | 197292 | model 50 – 25 |

Table 7 – Designing thickness of connection zone and continuity plate for Seri 2

| CASE1 | CASE2 | CASE3 | Panel zone ID | | |
|---|---|---|---|---|---|
| Thickness of continuity plate | | | $t_{pz}$ | $V_{pz}$ | |
| 2 | 2/2 | 200212 | 2 | 203319 | model 50 – 40 |
| 2 | 2/1 | 194477 | 1/9 | 199452 | model 50 – 32 |
| 2 | 2/1 | 197292 | 1/8 | 195757 | model 50 – 25 |

Table 8 – Designing thickness of connection zone and continuity plate for Seri 3

| CASE1 | CASE2 | CASE3 | Panel zone ID | | |
|---|---|---|---|---|---|
| Thickness of continuity plat | | | $t_{pz}$ | $V_{pz}$ | |
| 2 | 2/2 | 200212 | 1/8 | 211860 | model 50 – 40 |
| 2 | 2/1 | 194477 | 1/6 | 201661 | model 50 – 32 |
| 2 | 2/1 | 197292 | 1/6 | 209610 | model 50 – 25 |

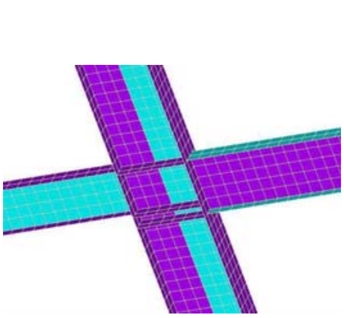

**Figure6** specimen with straight continuity plate

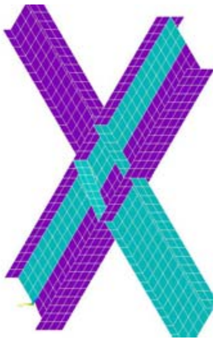

**Figure 7** specimen with inclined continuity plate

## 4. NUMERICAL RESULTS

Analyses of defined models were done after considering and employing mentioned issues in the pervious chapters. These analyses were fulfilled for 27 models .type of analysis is nonlinear and static that is effects of buckling and large displacement were included. Von misses failure criteria which is correct for ductile material was employed [11]. Results of analyses consist of moment hystertic curves vs. panel zone shear strain which have bean done for 27 models. These results have been shown in fig 8 to 10. Procedure of obtaining distortion is in reference [12]. Also for getting partial ductility factor through hystertic results see next chapter. This result is basic for comparing and judging on performance of arrangement of continuity plate in panel zone. And these ratios are comparable with result of FEMA273. For instance, some of figures of models which are buckled are shown in fig16,17,18. For example in fig. 18 it can be seen that the maximum amount of stress reached to 5196(kg/cm2) in column flange connected to smaller beam.

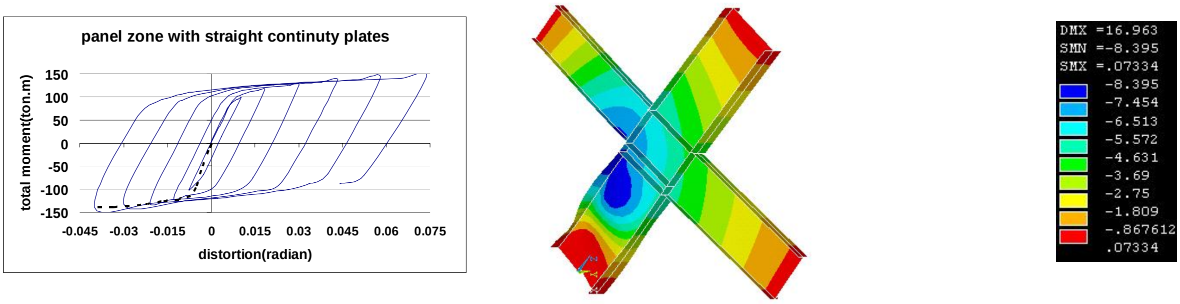


**Figure 8** Seismic behavior curve of panel zone with straight continuity plate, and buckled shape.

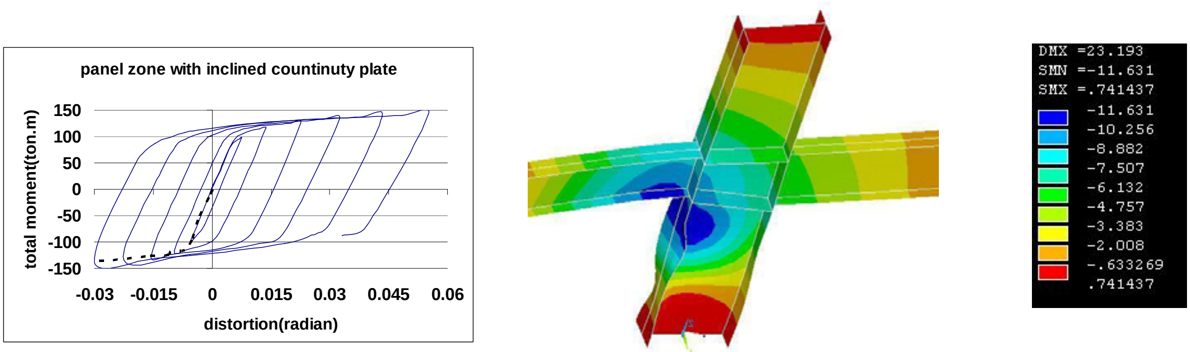


**Figure 9** Seismic behavior curve of panel zone with inclined continuity plate, and buckled shape.

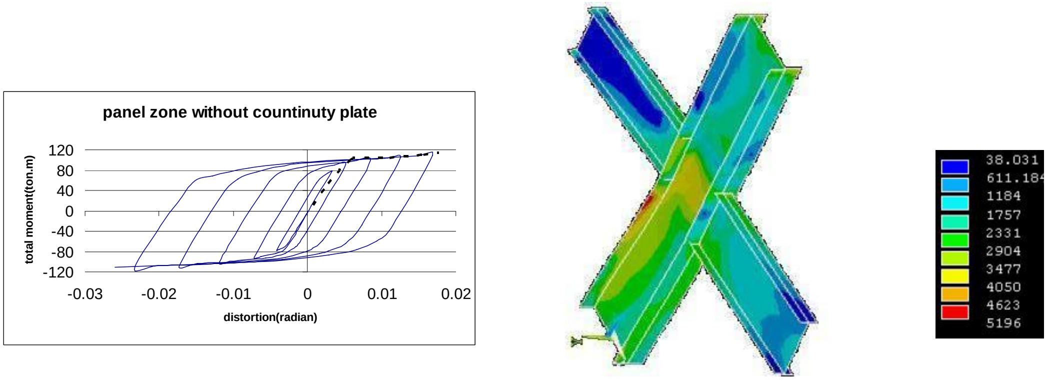


**Figure 10** Seismic behavior curve of panel zone with out continuity plate, and buckled shape.

## 5. CONCLUSION

The partial ductility ratio for panel zone could be obtained by using back bone curve drawn on hystertic loops of seismic behavior. The procedure to obtain the partial ductility ratio from seismic behavior curves , consists of drawing back bone curve and finding the rupture point (which is the end point) of back bone curve and yield point from idealized curve and dividing rupture point to the yield point. This ratio is partial ductility ratio. That is used for evaluating and retrofitting of structures. Partial ductility ratios of analytical models are presented in the following figures.

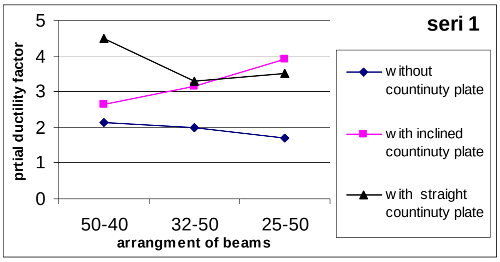


**Figure 11** partial ductility factor for Seri 1

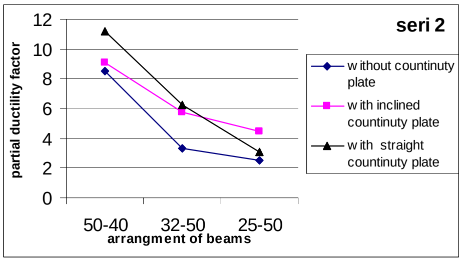


**Figure 12** partial ductility factor for Seri 2

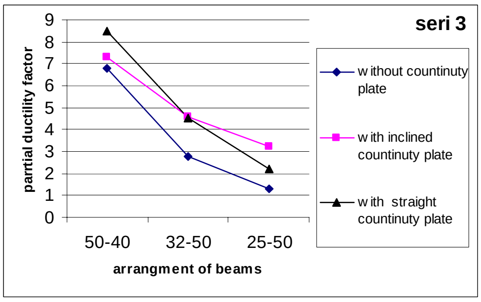


**Figure 13** partial ductility factor for Seri 3

Considering comparative diagrams, the results obtained from analytical evaluation of panel zones ductility under different conditions, including unequal beams and arrangement of continuity plate and thickness of column flange , are presented in this section as follows:

- observing and considering partial ductility factors in fig11 to fig13, it is apparent that increasing the difference of beam height, can cause decrease of partial ductility factor, even presence or absence of continuity plate is not effective in overall declining trend of partial ductility factor. But in ser1 that needs continuity plate according to IBC2000, presence of inclined continuity plate for specimen 50-25 Is more effective than the straight continuity plate; in general, in seri1 as the difference of height of beams increases, use of inclined continuity plates can enhance partial ductility factor of panel zone.

- Considering fig 11 to 13 in three series, it is understood that the presence of continuity plate with both of arrangements can improve ductility factor, despite of the fact that the series 2 and 3 do not need the continuity plate according to IBC2000. In brief, presence of continuity plate increases partial ductility factor globally .and putting continuity plate on panel zone in every case has technical justification.
- Considering fig 11 to 13 in three series, it is observed that the use of inclined continuity plate in cases that difference of height of beams is dramatic, is more effective than straight continuity plate. Specially when beam height of one side of column is half or less of the beam height of other side of column, inclined continuity plate has more partial ductility factor than straight continuity plate.
- According to last paragraph in three series, one can see that the straight continuity plate in cases which have little difference in height of beams, is more effective than inclined continuity plate, for example this matter is critical for specimen 50-40 in seri1. Although, type of arrangement of continuity plate in specimen50-32 is not important.
- As it was informed in figures 11 to 13 despite of view of FEMA 273 that determines a constant partial ductility factor for panel zone in all of geometry cases, the ductility of this element depends on the geometry and arrangement of continuity plate.

Finally, it should be mentioned since all of the results are originated from analytical model, it is obligatory to set series of experimental model to examine the correctness of analytical model.

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