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Introducing an Innovative Column Splicing Technique for Steel Structures

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Abstract

In construction of steel structures, in many cases because of the shortage of profile length, changes in column section in elevation, or other conditions it is necessary to patch the column parts. The importance of the subject is so obvious that many books and building codes introduce methods and regulations for this subject. In spite of all provisions, the column patch is one of the weakness points of the construction.
Foroughi proposed a type of splicing design called a sliding patch which is more suitable for I section columns as well as other shapes of column sections. The procedure is as follows; first, the web of the lower portions of the column is cut to a proper size and removed. Then, the upper part of the column that is usually of smaller size is placed inside the flanges of the lower portion and the two parts are welded. Consequently, the flanges of the lower part play the role of a patching plate and because of continuity, the required length of the patching plate will decrease to a half requiring less welding and cutting. In addition because of continuity of the flanges the quality of the patch is higher. Recently, Foroughi and colleagues studied these types of splicing under cyclic loading. In these studies, the patch is modelled using finite elements considering material and geometrical nonlinearities. The program ANSYS is employed and the models analysed under cyclic loading. All samples are modelled and studied in both traditional form and proposed form. Then the results are compared. A comparison of the results shows that the proposed method demonstrates better behaviour than traditional methods. Also, the proposed method requires less cutting and welding.

Keywords: splice, patch, steel structure, sliding patch, connection, welded connection.

1 Introduction

A structure is a combination of structural elements related to each other by connections. If the connections are not designed correctly and carefully, they will act

as weak unit of this chain and endanger the safety and serviceability of the building. In design of the connection details the degree of accuracy observed must be at least the same as the main elements of the structure and even more carefully.
In steel constructions, sometimes it is necessary to splice the pieces of beams and columns to each other. The importance of the subject is so obvious that many books and building codes introduce methods and regulations for this subject [1, 2]. In spite of all provisions, the column patch is one of the weakness points of the structures [3]. Foroughi proposed a type of splicing design called sliding splice more suitable for I sections especially I section columns [4].Studies show the proposed patch, has a higher quality and lower cost and it is not more difficult compared to traditional methods [4, 5, 6].
In this research, we will concentrate on study of nonlinear behaviour of the sliding splices [4, 5]. This type of splicing is similar to splicing web and flanges by adding plates but instead of adding plates on flanges, the web of the lower section will be cut long enough and the upper section will be placed inside it. For web splicing, stiffener plates can be used. The sliding splicing can be employed in cases of either equal or different size profiles. In this paper, the splicing of different size sections will be considered.
Due to lab restrictions, the finite element method was employed for modelling [6] and the behaviour of the connection to failure state was studied. For analyses, ANSYS software was employed considering material and geometrical nonlinearities. Cyclic loading was applied. Due to lack of test results, for validation, the work done by Foroughi et al [7, 8] on beam to column connection tested by Mazroui et al [9] was considered. Figure 1 shows a good agreement between finite element model "F7-m9 (new3)" and test results "F7" [9, 10].

2 Sample definition

The studied sample is a column in a 5 storey building. The column height is 360 cm. Considering the profile length (12 m), the splicing will take place at 1 m above the fourth floor .The lower section is IPB280 and the upper one is IPB240.
In this study, 4 different types of splicing is introduced and modelled. There is a splicing of different size sections (Fig. 2) that connected in different forms using regular and sliding type. According to Figure 2, Sample S2, connection with cover plates on the web and flanges; sample SS2, splicing with sliding connection and cover plates on the web; sample STS2, connection with cover plates on flanges and stiffener plates on the web; sample STSS2, sliding splicing and stiffeners on the web.

Acting forces at splice point are;
Axial force: N=643.4 KN;
Moment: M= 4853 KN-Cm;
Shear force: V=37.56 KN

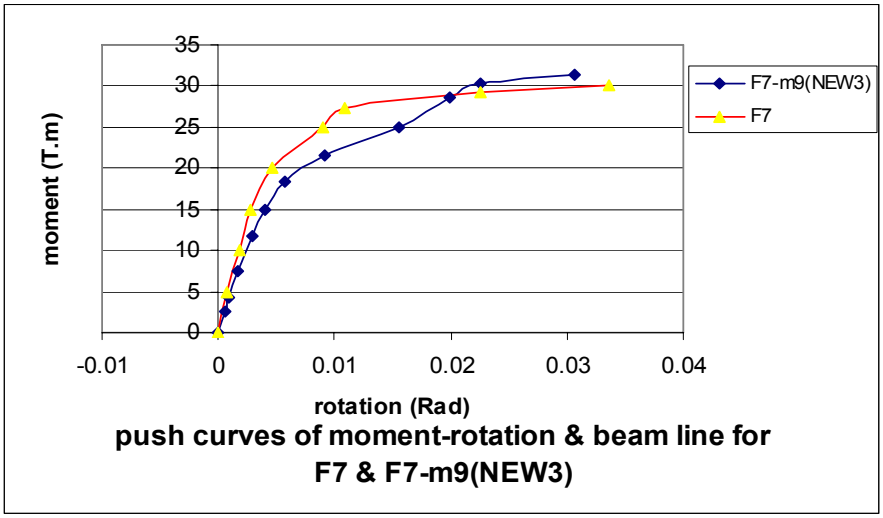


Figure 1: Comparison of moment-rotation curves of sample (test and analytical results)

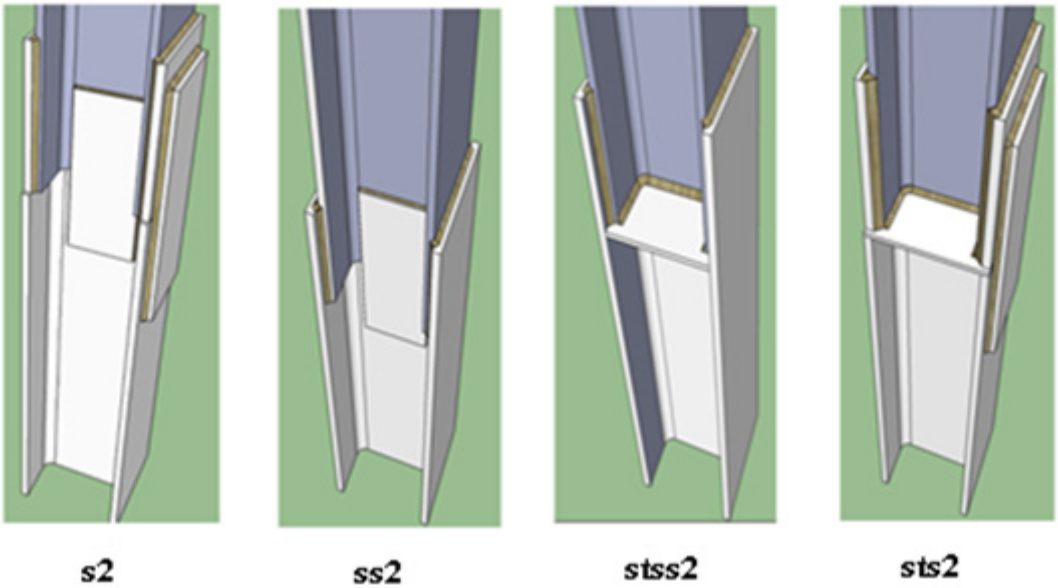


Figure 2: Samples S2, SS2, STS2, STSS2

In traditional connection with cover plates on the web and flanges, filler plates is used to fill the difference in sizes. The plates are designed according to Iranian Connection Code [11] as follows:

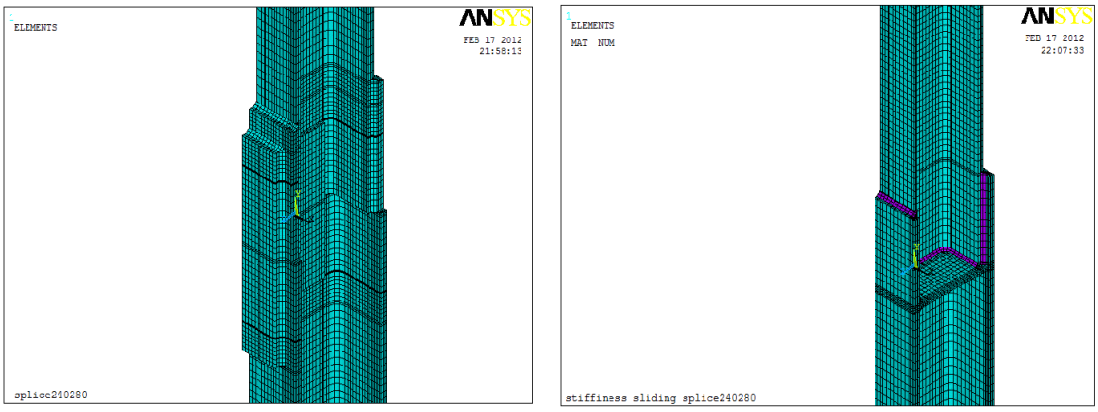
Flange plate:	2PL560×200×22	a=10mm
Web plate:	2PL400×160×8	a=4mm
Filler plate:	2PL340×260×10	a=8mm

Where "a" is the welding thickness.

In case of sliding splicing (SS2 and STSS2), for design of flange connection, the width of connection plate is actually the width of inner column flange. Thus, the cutting length for lower section would be as follows:
Necessary welding length for upper section = 72.6 cm
Welding length = (72.6-24)/2 =24.3 ≈ 25cm
Thus, necessary cutting length is 25 cm.
Since the web of lower section is cut and the upper section is placed inside it, using filler plate is not necessary. For example in this sample, the height of IPB240 is 24cm and the web size of IPB280 is 24.2cm having only 2 mm difference.
In cases that this gap is larger, the flanges of lower section can be bent so that fit the connection. Thus, the filler plate is not needed. Usually, the difference in lower and upper sections is not large but if it is large, splicing with plate must be used. In samples STS2 and STSS2, instead of web plates, stiffener plates 280×280×10 mm are used.

3 Finite element models

In this study, samples were modelled with finite element method, using ANSYS software, considering geometrical and material nonlinearities. SOLID45 elements used for all steel members and CONTAC52 elements for any contact surfaces. For example, Figure 3 shows the finite element models of samples "S2" and "STSS2".



Finite element model of sample "S2"

Finite element model of sample "STSS2"

Figure3: Finite element models of samples "S2" and "STSS2"

4 Material

In this study, two types of materials are considered; welding material and steel material for sections and plates based on previous authors' research [10]. Stress-strain curves for these materials are shown in Figure 4.

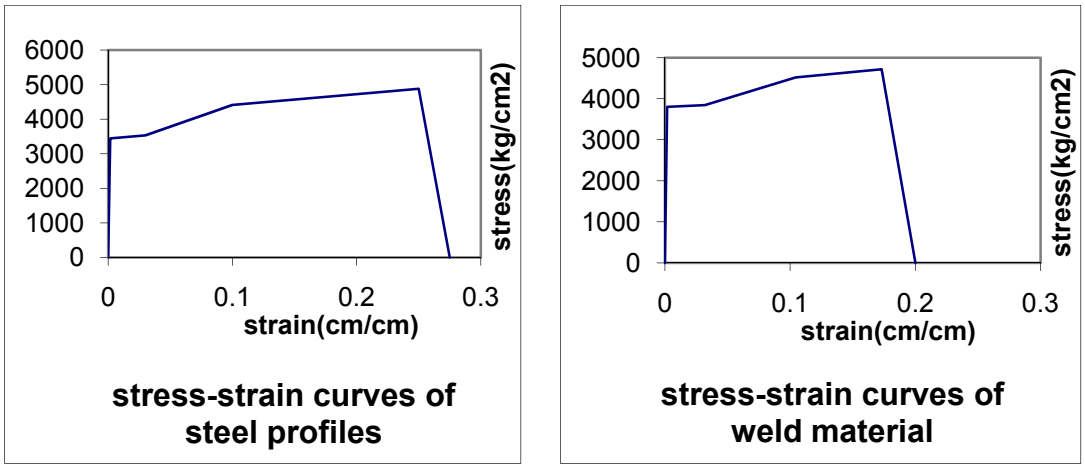


Figure4: Stress-strain curves of steel profiles and weld material

5 Loading

For lateral loading, cyclic displacements are applied. Loading is applied according to AISC [12] at upper end of column in web direction. The vertical load 643.4 KN is applied in form of 6.07 KN/cm2 at the upper surface of the column (elevation 3.6m). All degrees of freedom at lower section of the column are fixed so that resembles fix support. Figure 5 shows the cyclic loading at the upper end of the column.

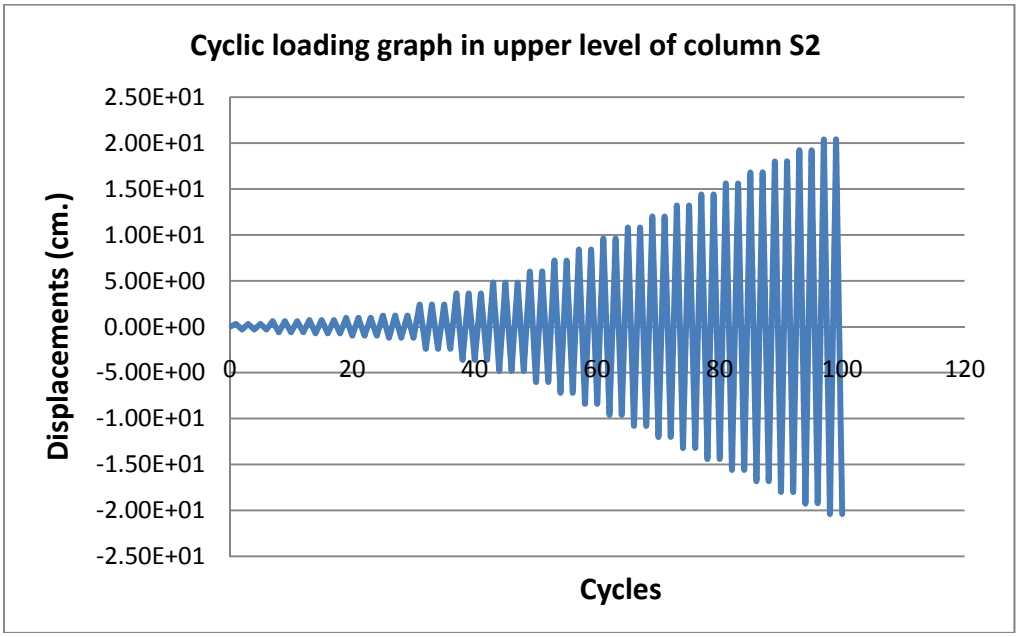


Figure5: Cyclic loading graph in column S2

6 Results

Figure 6 shows the cyclic moment- rotation curve for columns under study and figure 7 shows envelope curves of moment- rotation for splices in these samples. It

can be observed that all samples behave desirably. Also the sliding splices can withstand more loading cycles.

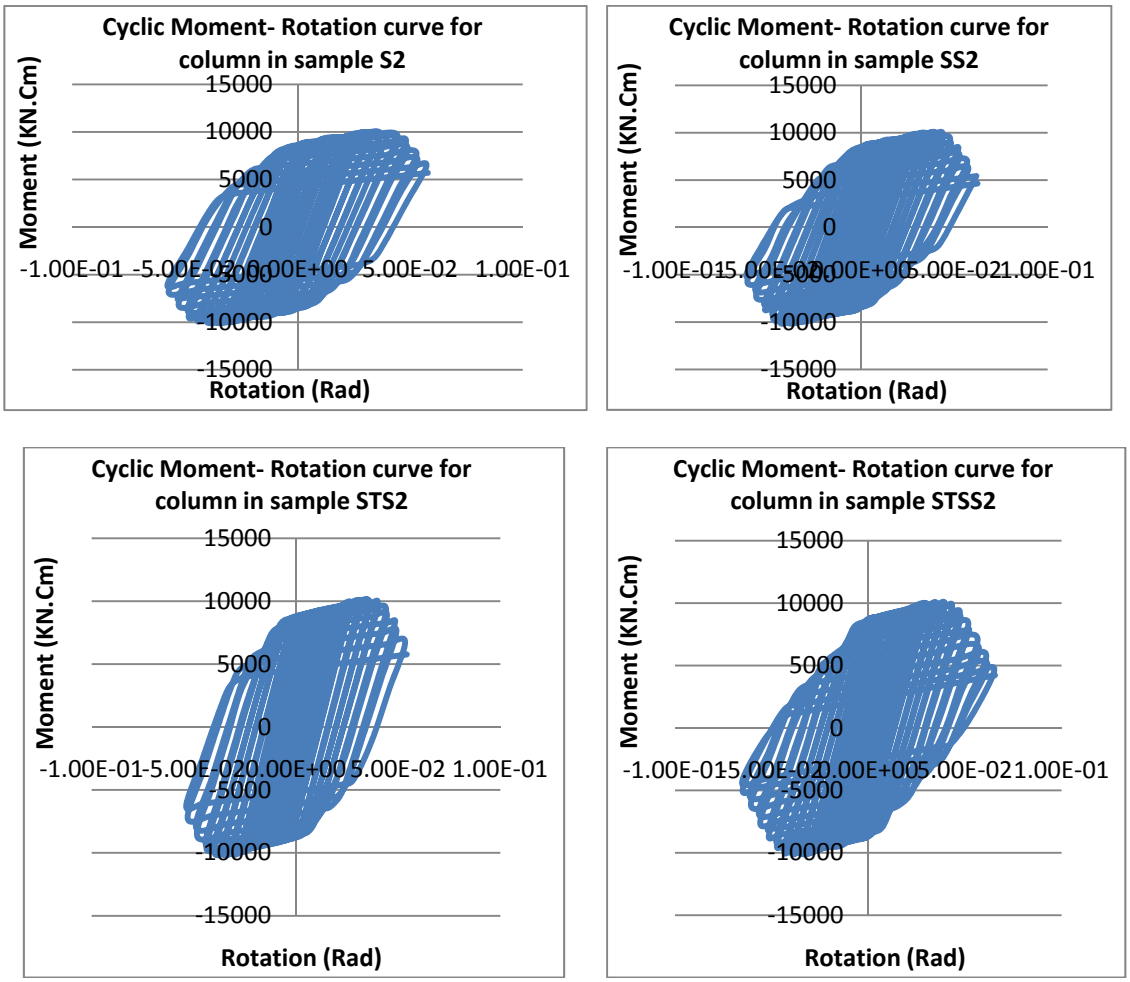


Figure 6: Cyclic moment-rotation curves

Fig (8) shows contours of Von-Mises stress in sample STSS2 demonstrating maximum stress at column base while at splicing region there is no stress concentration higher than yielding stress. Figure 9 shows the equivalent plastic strain in whole column demonstrating large plastic strains at support region. Also it is shown that there is no plastic strain concentration at splicing region. It should be noted that in other samples the stress and strain curves show almost the same behaviour.

7 Comparing studied samples

Studying table 1 shows that sliding splices withstand more loading cycles compared to traditional ones. For example, sliding splice with stiffener can carry 6 loading cycles more than traditional one.

To compare the ductility, ductility of traditional splice in case of unequal size sections is chosen as a base and other samples are compared. Ductility of the samples is shown in table 1. The table shows that applying stiffeners can elevate the ductility slightly. Also, the sliding splices enter nonlinearity later than equivalent traditional ones. Considering Von-Mises stress and plastic strain, show that none of the sliding splices experience stress concentration higher than yielding stress and neither large plastic strains. Usually, maximum stress and maximum equivalent plastic strain occur in support region. Figure 9 shows moment-rotation curves which conclude that column splice with sliding connection and stiffener plates can carry largest rotation and behaves better than others.

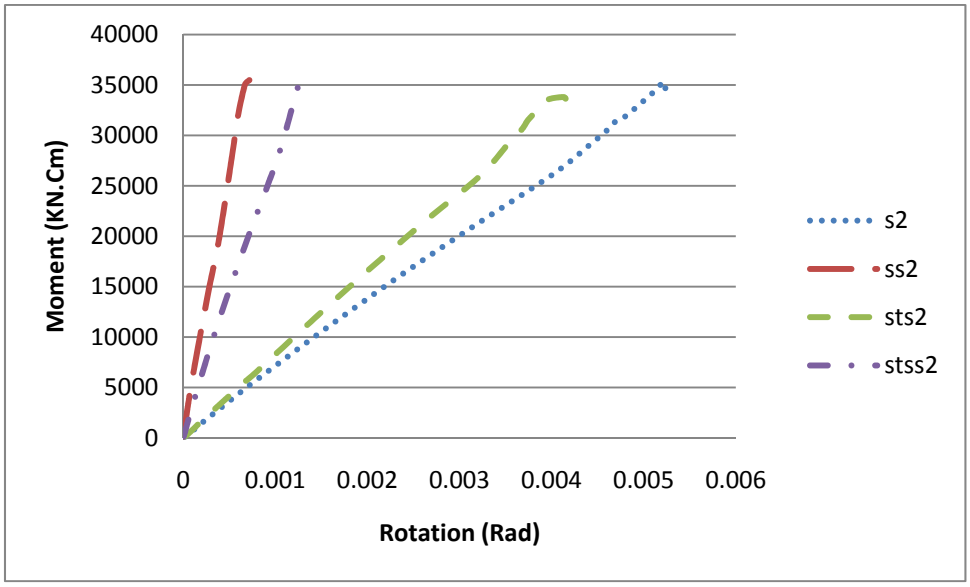
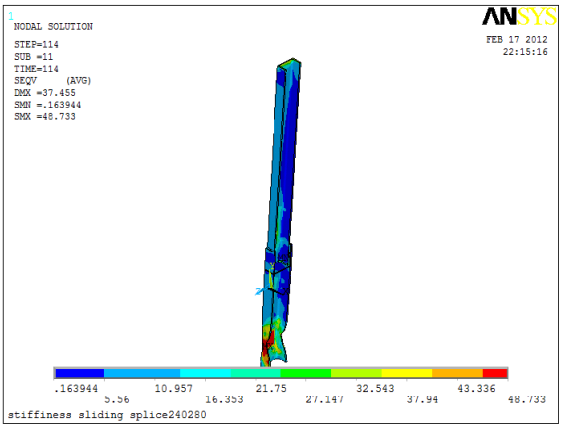
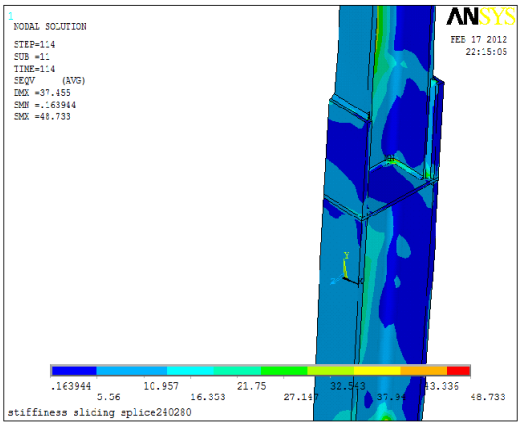


Figure 7: Comparative envelope moment-rotation curves



Von-Mises stress contour in sample STSS2



Von-Mises stress contour in sample STSS2 (connection region)

Figure8: Von-Mises stress contour in sample STSS2

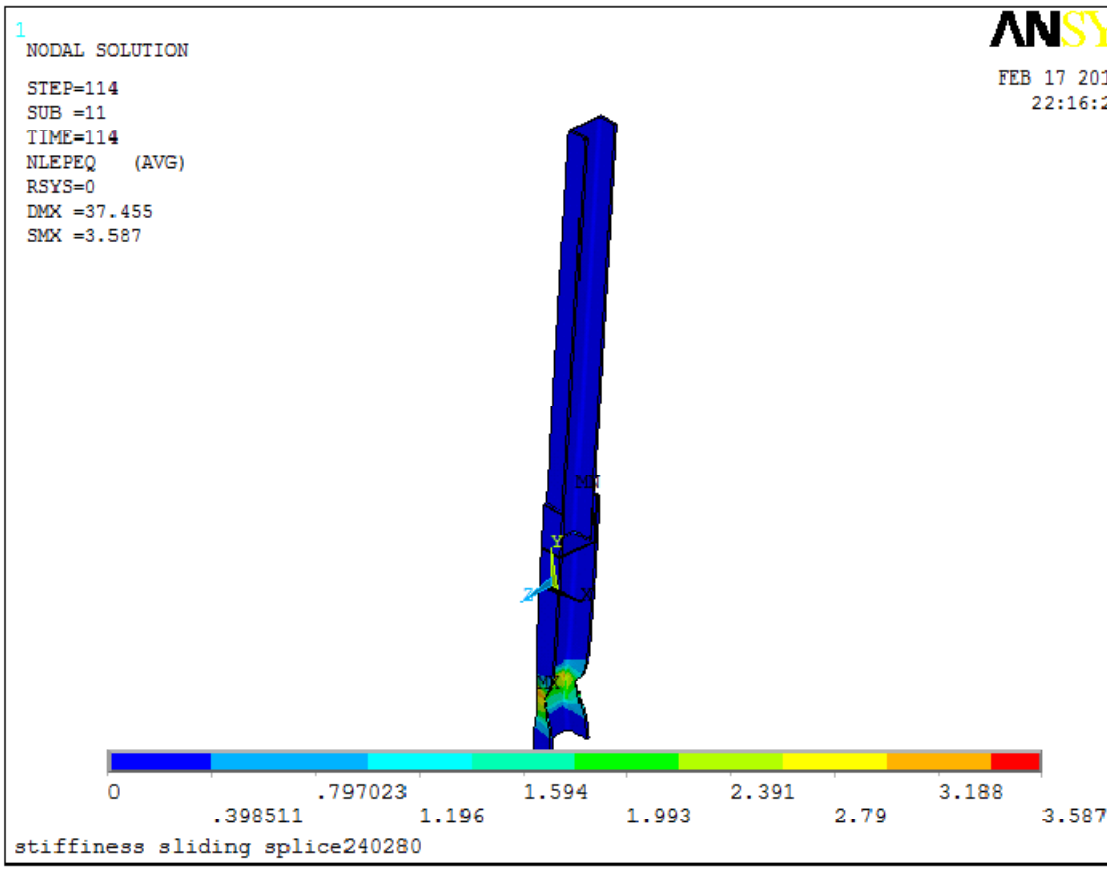


Figure 9: Equivalent plastic strain contour in sample STSS2

Sample	θ_y	θ_u	M_y	M_u	μ	μ/μ_{s1}	Last Cycle No.
S2	1.1e-2	4.6e-2	7250	9913	4.27	1	51
SS2	1.2e-2	5e-2	7300	9894	4	.94	54
STS2	1e-2	4.5e-2	7800	9998	4.6	1.08	51
STSS2	1.2e-2	5e-2	7800	10000.9	4.17	.97	57

Table 1: Ductility of the samples

8 Comparing construction tasks and expenses of different connections

Considering table 2 shows that sliding splices require less welding and cutting compared to equivalent traditional ones so that in case of different size sections the cost will decrease by 70%and 86%. Also, in case of different size sections have no construction difficulties.

Samples	Cutting (cm)	Welding (cm)
S2	542	492
SS2	74.2	148.4
Reduction percentage	86.3%	69.8%
STS2	536	488
STSS2	74.2	148.4
Reduction percentage	86.2%	69.6%

Table 2- Comparison of welding and cutting cost in samples

9 Conclusions

In this paper, sliding splicing for columns with different size sections with web plates and stiffeners are studied and compared with traditional ones. The results lead to the following conclusions:

- Sliding splices show better behaviour compared to equivalent traditional ones.
- Applying stiffener plates instead of web plates will improve the behaviour of traditional and especially sliding splices. In the case of different sized columns the sliding connection with stiffener plates in web could carry three more loading cycles than the same connection with web plates and six more cycles than the traditional connection with plates on web and flanges.
- There is no stress concentration higher than the yielding stress and large plastic strain. Maximum stress and strains occur in the support region.
- In all samples, plastic deformations occur only in the support region and there is no plastic deformation in the connection region.
- Sliding splices in both cases require less welding and cutting compared to traditional connections.

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