Research Article

Study on Influence of Geometric Parameters of Replaceable Links on Fatigue Behaviour of Steel Beam

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Abstract: Seismic activity is a sign of worry as it causes fatal damages to human and also to structures. Structure must exhibit excellent ductility when overloaded during a major earthquake and must be able dissipate large amount of energy to prevent collapse. Moment resisting steel frames are one of the major earthquake resisting system for steel buildings. Major drawback of system is its components get damaged during earthquake and repair work become uneconomical. This problem can avoid by providing replaceable links in beams of moment resisting frames. This study focuses on energy dissipating ability of replaceable links under cyclic loading. Scope of work is to obtain the promising configuration of replaceable links for steel beams. In this paper, nonlinear finite element analysis has been performed on 32 configuration of replaceable links using ANSYS-Workbench to obtain energy dissipating ability of cantilever steel beam with replaceable links. Cantilever steel beam with link has been analysed by keeping beam size constant. Position of the link has been varied to study the performance of link under cyclic loading. Location and dimension of link sections were chosen on the basis of design recommendations for reduced beam section concept. Maximum stress was observed in link portion alone but the portion of beam experiencing very less magnitude of the stress compare to the link portion. Energy dissipation by the beam was increased with increase in value of 'a/bbeam' up to a/bbeam=0.7b and it gradually decreased for the values greater than a/bbeam=0.7 for all the variations of 'S/dlink'.

Keywords: Steel beams, Replaceable links, Moment Resisting Frames (MRF), Energy Dissipation

1. Introduction

Earthquake is one of the natural hazard that causes catastrophe to both buildings and humans life. Over last two decades the occurrence of earthquake has caused defects on high rise building this has been aspiration for using earthquake resistant structure, the main objective of earthquake resistant construction is to erect structures that shows resistant to lateral loads then the conventional counterpart. The activity which is connected to the structure during an earthquake is usually ground movement with horizontal and vertical segments [14]. The component of the earthquake resistant structures is designed to resist gravity and horizontal loads. The vertical component of the seismic action is usually about 50% of the component of horizontal, but except in the area of the epicenter of an earthquake where it can be generally the same order.

Currently, there are few theory in earthquake engineering, making use of experimental outcomes, computer stimulation and perception from past seismic action. These led to many growths in technologies such as base isolation, vibration control etc., and one among them are the use of shear links [10]. Earthquake Resistant Structures (ERS) minimizes the loss of structure and also prevent the collapse of building. ERS are designed to resist the earthquake loads that occur continuously. There are two reasons by which seismic activity may be resisted:

Choice one is structures with higher sections that they are subjected to elastic stress and another choice is smaller sections of a structure are planned, according to various plastic zones.

A structure designed to according to choice one will be denser and add up to gravity loads-which may not provide safety side to cover seismic loads. The choice two components are designed such that they undergo less deformation under cyclic loadings and selected zone are plastically deformed and dissipate absorbed energy [3].

2.Background Theory

MRFs were used in early 90's were having bolted and welded flange sections. This raised a query during earthquake in Northern ridge and brittle cracks were observed in the welded sections. From the outcome of these observations of the failures, various schemes were developed to increase performance of the connections. The generally accepted solution was the reduced beam section concept, in which flanges of the beam are weakened at a small distance away from the face of the column [7]. The plastic hinge is developed within the reduced beam section, thus reduces the forces experienced by the connections of structural elements, including the connection welds. A typical example of a RBS connection is shown in “Fig 1” [13].

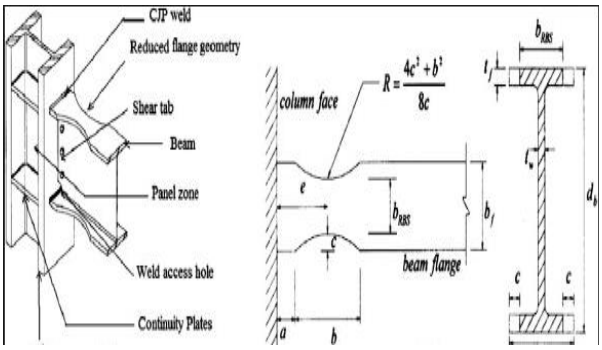

Fig. 1. Reduced beam section [6]

Drawbacks of the RBS concept was eliminated by providing replaceable links at the portion of expected plastic hinge in the beam as shown in “Fig 2”.The weakened beam is at a small distance away from the fixed face, the plastic hinge is developed at the link section. Instead of reducing the beam section, replaceable links are introduced at the locations of expected inelastic action [13]. The other structural components in the frame are then designed to remain elastic under the forces associated with yielding of the link. The link concept was first introduced by Balut and Gioncu (2003) to facilitate-repairs of Moment resisting frames. Since the inelastic deformation is concentrated within the link, it allows quick inspection and replace of damaged links and also it minimizing the construction time of the structure. It also allows for independent control of beam stiffness and required strength, resulting in more efficient structures. Furthermore, it allows welding of critical elements to be done in the shop, considerably improving construction quality and reducing erection time.

The experimental work is carried out on non-linear replaceable links in moment resisting frames (Yunlu Shen, 2011) and some author work on MRF (Shen, Yunlu, 2009). The MTS(Mobile testing machine) was used to apply cyclic loading (Nabil Mansour, 2011), (Yunlu Shen, 2011).

The Numerical work is carried out on non-linear replaceable links in moment resisting frames [14, 16]. ANSYS software was used to model the specimen and monotonic, cyclic loading analysis were conducted**.**

Limited studies were found on numerical validation of experimental work on steel beam with replaceable links and also studies on influence of geometric parameters on fatigue behaviour of steel beams with replaceable links have not done till date.

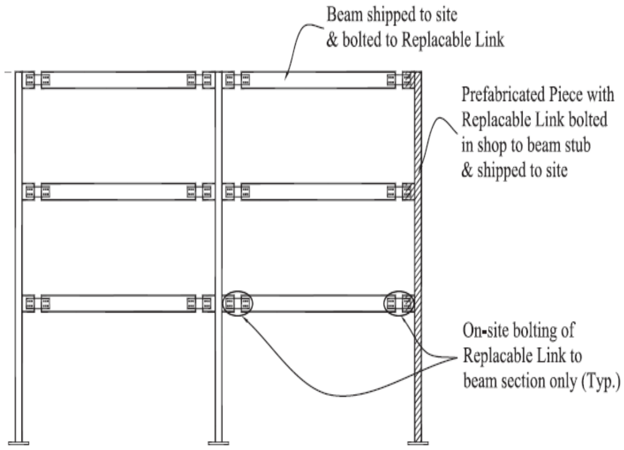

Fig. 2. Moment resistant frame [14]

The scope of the work is to study the behaviour of cantilever steel beam with replaceable link and also obtain optimum dimension and location of the replaceable link. In this work displacement controlled cyclic repetitive load has been applied at the free end of the steel cantilever beam. Hysteresis curve was plotted for load and displacement. Energy dissipation capacity was compared based on the area of the hysteresis curve.

3.Validation

To validate the simulated model of steel beam with replaceable link, Experiment data has been taken from the paper *“**Seismic Design and Performance of steel Moment Resisting Frame with Non Linear Replaceable links**”* [16]

Experiment details:

- Length of the beam is 3.152m,
- Beam size is W490*217
- Plate thickness of plate section is 9.5mm,
- A490 bolts bolts are used.

The geometry of the steel beam with a replaceable link was first modelled using the CATIA V5 software which is given in “Fig. 3”.

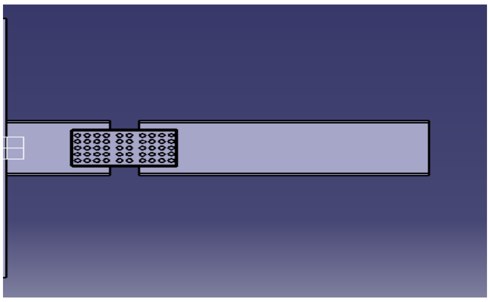

Fig. 3.CATIA V5 model

Then imported into the finite element analysis program ANSYS Workbench Version 15

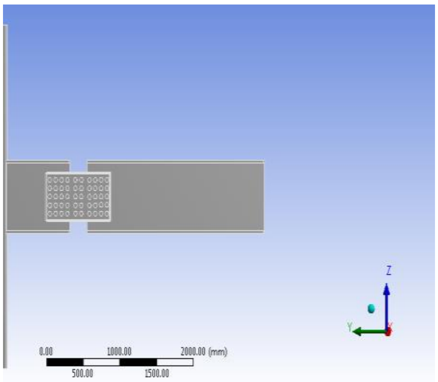

Fig. 4. ANSYS model

Material properties of the steel beam with replaceable link are Elastic modulus = 200000MPa, Density of steel = 78.50 kN/m^3, Poisson’s ratio = 0.3. The beam is fixed at left end and the cyclic loading (displacement) was applied at the free end of the beam. The loading sequence has described in AISC 341-10. The stress contour was captured after link attained the plastic deformation is as shown in “Fig 5”

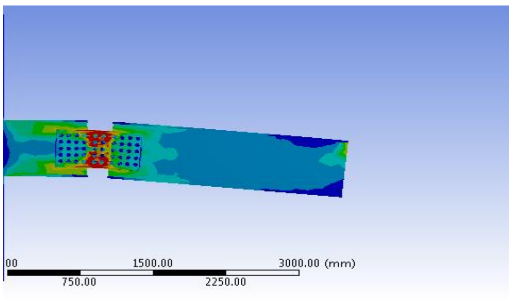

Fig. 5. Stress contour

Table 1 Results of validation

S I No	Experimental Results in kN [16]	Numerical Results in kN	Percentage difference
1	123	127	3.14
2	175	190	7
3	350	357	2
4	400	417	4

From the Table 1, it can be observed that there is only 2% to 7% difference between experimental results [16] and numerical results. Hence same methodology was adapted to perform the parametric study.

4. Parametric Study

In this parametric study beam size and depth of the link has kept constant. The position of the link has been varied to study the performance of link under cyclic loading. Location and dimension of the link sections were chosen on the basis of design recommendations for reduced beam section. For this study plate thickness of the replaceable link was kept constant. Geometric details of the beam considered for the study are given in Table 2

Table 2 Dimension details of parametric study

S I No	Components	Dimension details
1	Beam (ISMB 450)	Depth of beam = 450mm
		Width of flange = 150mm
		Thickness of flange = 17.4mm
		Thickness of web = 9.4mm
2	Depth of link section	350mm
3	Plate thickness of link section	8 mm
4	Bolts	16 mm diameter bolts at 70 mm spacing

Beam and link dimensions considered for the parametric study are given in Table 2. Geometric parameters of the beam and replaceable links are as shown in the "Fig. 6".

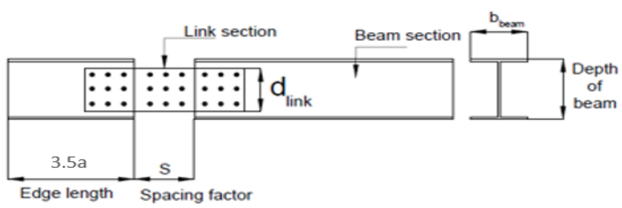

Figure 6 Parametric model

Table 3 Parameters Considered For The Analysis

Model No	Plate thickness of link section in mm	$\frac{a}{b_{beam}}$	$\frac{S}{d_{link}}$

1	8	0.2	0.5
2			0.75
3			1
4			1.25
5	8	0.3	0.5
6			0.75
7			1
8			1.25
9	8	0.4	0.5
10			0.75
11			1
12			1.25
13	8	0.5	0.5
14			0.75
15			1
16			1.25
17	8	0.6	0.5
18			0.75
19			1
20			1.25
21	8	0.7	0.5
22			0.75
23			1
24			1.25
25	8	0.8	0.5
26			0.75
27			1
28			1.25
29	8	0.9	0.5
30			0.75
31			1
32			1.25

5. Results And Discussions

In this section of the paper hysteretic response of all 32 models of steel beams with replaceable links are compared. Performances of all the specimens are compared based on the energy dissipation capacity i.e. total area of the hysteresis loop. Typical representation of stress contour and hysteresis graph as shown in “Fig 7 and 8”.

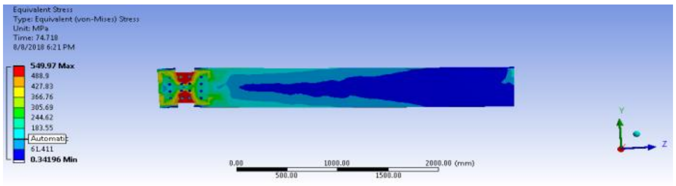

Fig 7 Stress contour of Model 1A

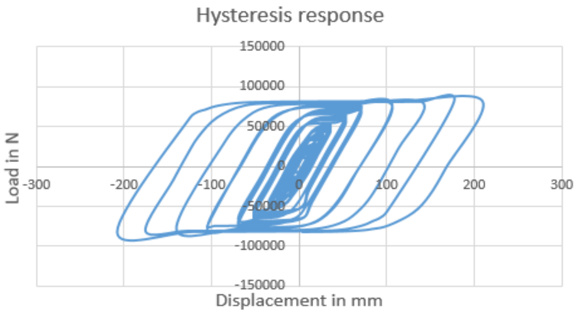

Fig 8 Hysteresis response of model 1B

It can be observed from the stress contour diagrams given in "Fig 7", maximum stress is developing in the link portion. Other portion of the beam experiencing very less magnitude of the stress compare to the link portion. From this observation it is clear that energy absorbed by the structural system is dissipating through the deformation of the link alone.

From the study, it is observed that, hysteretic response of all the models are identical, pinching of hysteresis loop has not been observed in any of the model. This indicates that presence of replaceable link in structural system increases the energy dissipation ability. But there is difference in the energy dissipating ability i.e. area of the hysteresis loop, for different geometry of replaceable links, and it is given in the Table 4.

Table 4 Parametric Study Results

Model No	Plate thickness in mm	a/b_{beam}	S/d_{link}	Displacement in mm	Load in kN	Energy dissipation kN-mm	Permanent deformation in mm	Retained deformation in mm	Energy retained in the system in kN-mm
1	8	0.2	0.5	208	93	49868	166	43	1999.5
2			0.75	196	87	42096	117	79	3436.5
3			1	185	82	38456	111	74	3034
4			1.25	180	80	32465	105	75	3000
5	8	0.3	0.5	216	108	56694	180	36	1944
6			0.75	201	88	49094	177	44	1936
7			1	196	84	40204	150	46	1932
8			1.25	179	82	34990	128	51	2091
9	8	0.4	0.5	210	102	50686	168	42	2142
10			0.75	198	97	46897	148	41	1988.5
11			1	183	92	42679	140	43	1978
12			1.25	178	92	38406	130	49	2254
13	8	0.5	0.5	220	100	55190	176	44	2200
14			0.75	208	100	52843	166	42	2100
15			1	185	99	41568	135	51	2524.5
16			1.25	176	97	40144	125	51	2473.5
17	8	0.6	0.5	246	104	70384	210	36	1872
18			0.75	225	103	58513	180	45	2317.5
19			1	198	101	51116	150	48	2424

20			1.25	176	100	39691	144	36	1800
21			0.5	248	110	75197	210	38	2090
22	8	0.7	0.75	233	104	64183	187	46	2392
23			1	220	103	60266	176	44	2266
24			1.25	195	101	46146	148	48	2424
25			0.5	248	107	64236	210	38	2033
26	8	0.8	0.75	176	105	53348	138	39	2047.5
27			1	166	104	44196	125	41	2132
28			1.25	142	100	31284	84	58	2900
29			0.5	176	110	55426	140	36	1980
30	8	0.9	0.75	162	107	50236	120	42	2247
31			1	141	102	45216	102	44	2244
32			1.25	138	100	42136	83	55	2750

- From Table 4, it can be seen that the load and displacement are decreasing with the increase in value of 'S/d_{link}' for all the variables of 'a/b_{beam}'
- Energy dissipated through the link and permanent deformation are also decreasing with the increase in value of 'S/d_{link}' for all the variables of 'a/b_{beam}'
- Deformation regained by the link and energy retained in the are increasing with the increase in value of 'S/d_{link}' for all the variables of 'a/b_{beam}'

A. Energy dissipation ability of link with the variation of 'a/b_{beam}' and 'S/d_{link}'.

This section presents the variation of energy dissipation through the link for variation of 'a/b_{beam}' and 'S/d_{link}'.

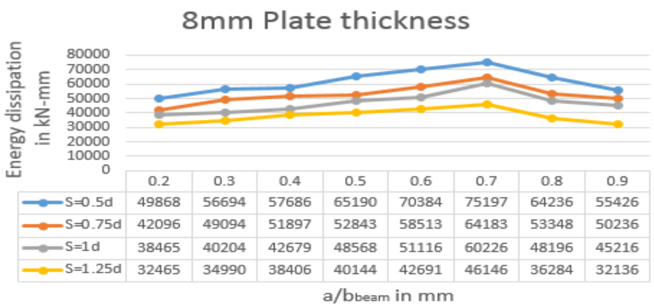

Fig 9 Comparison of Energy dissipation versus a/b_{beam} for 8mm plate thickness

- From "Fig 9", it can be observed that energy dissipated by the beam is minimum for the beam to beam spacing factor i.e. S/d_{link}=1.25.
- Energy dissipation by the beam is decreasing with the increase in the value of 'S/d_{link}'
- Energy dissipation by the beam is increasing with increase in value of 'a/b_{beam}' up to a/b_{beam}= 0.7 and it is gradually decreasing for the values greater than a/b_{beam}= 0.7 for all the variations of 'S/d_{link}'
- From the "Fig 9", it is clear that optimum value of 'a/b_{beam}' was found to be 0.7b for all the variables of plate thickness of the links.

6.Conclusions

- Cantilever beam with edge length factor a/b_{beam} = 0.7 dissipating energy is 38% more energy compare to other edge length factor (a/b_{beam}) for all the variation of S/d_{link}
- The 0.7 width of beam section and 0.5 depth of link section yielded better result in all the models

The combination 0.7b and 0.5d would be better geometric design for using in the structural components..

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