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A CRITICAL REVIEW ON REPAIR, RETROFITTING AND STRENGTHENING OF STEEL STRUCTURES

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Abstract: **Recently, a lot of steel structures have experienced severe natural disasters and also various types of terrible collapse have occurred. So, to protect their collapsion, Repair and Retrofitting are needed. These paper reviews the various methods, types or ways of repairing and retrofitting of steel structures. This paper also mirrors the different techniques of strengthening of steel structures which are very important to improve the load bearing capacity of steel structures. In this paper, it is also tried to create public awareness for conducting the overall work of repairing, retrofitting and strengthening safely. At the end of this paper, a concluding remark is also included.**

Keywords: Repairing, Retrofitting and Strengthening.

I. INTRODUCTION

Due to many reasons, steel structure is becoming popular day by day throughout the world. This structural steel may be damaged by overload, high wide load impacts, fire or seismic effect (Alberta transportation report, 2004 [1]). If this damaged condition is unrepaired, then the condition of the components of this steel structure may be deteriorated. Due to this reason, Repairing and retrofitting is needed to overcome such deterioration. "Iranian Code of Practice for Seismic Resistant Design of Building" [2] (standard no.2800) published in 1988 has motivated the civil engineers to strengthen the existing steel buildings (Bazaz B.J. (2000) [3]). It is true that a large number of buildings made with steel and concrete may vulnerable to seismic effect because of ignoring proper building code. So, if this steel structure can be rearranged with special technique so that it can carry more loads. So, this rearrangement of the steel structure is called strengthening. The main objectives of this review is to gather the methods of repairing, retrofitting and strengthening of steel structures which can easily be executed in any practical problems.

II. REPAIRING OF STEEL STRUCTURES

Due to many reasons, steel structure may be repaired. So, there are many methods to repair steel structures. So, there are many methods to repair steel structures. This may depend on location of the crack, type of crack, type of repairing work etc. So, in this portion of this article, causes of repairing, methods of repairing work, some practical examples and recommendations are included. So, some reasons which are liable to such type of repairing work are discussed below:

FATIGUE

The main cause of fatigue is the creation of cracks in members or connections of steel structures (Fisher and J.W. (1984), [4]). It can be caused due to cyclic service loading (Maddox and S.J. (1991) [5]). Fig. 1 shows the development of fatigue situation in I-beam (FHWA, 2013 [6]). This picture (Fig.1) also shows the fracture surface of an I-beam flange created by fatigue-cycling [7].

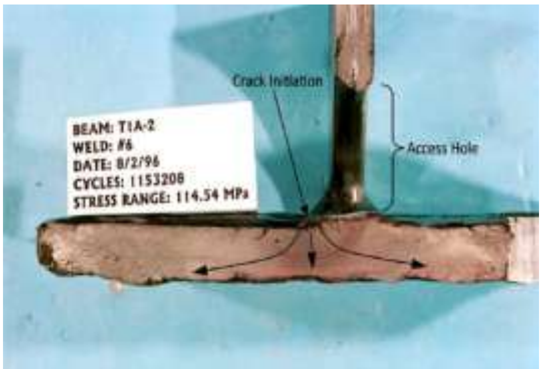

Figure 1: The fracture surface of an I-beam flange. Photo courtesy of US coast Guard (Kelly et al. (1997) [8]).

FRACTURE

Fracture is a common phenomenon of steel structures. It is occurred when the rapid extension of the crack is happened (Dexter et al. (1999) [9]). Fatigue and fracture are different. The large extension of fatigue may cause fracture. The fracture of the members of steel structures may cause total collapsion of this structure. When the loads are applied at the first time of the steel structures then the fracture can be caused (FHWA, 2013 [6]). The following picture shows the fracture surface of a bridge in Cherokee country, Iowa. The top part shows the actual fracture surface where the horizontal element is the bottom girder flange, and a vertical element is the girder web. It is possible that fractures can occur directly without previous fatigue crack growth after years of service as was the case in the Hoan Bridge (Wright et al. (2001) [10]). Brittle fracture can occur at high constraint details with little or no warning impending fracture (FHWA, 2013 [6]). For example, in 1967, the Point Pleasant Bridge over the Ohio River in West

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Virginia, commonly referred to as the Silver Bridge, collapsed due to brittle fracture of one of the non-redundant eye bars supporting the main span suspension system (Bennett et al. (1974) [11], FHWA, 2013 [6]). Figure 2 shows the girder flange fracture from Cherokee County, Iowa Bridge.

Figure 2: Girder flange fracture from Cherokee County, Iowa Bridge.

ROUGH HOLES

These are observed in truss members during ultrasonic testing and inspection. This is clear indication of the starting of fatigue cracks. When at a specific point, the connection is required in steel structures, then a hole is drilled. This is called open holes (Alberta transportation report, 2004 [1]).

HOLE DRILLING

Hole Drilling is another famous method for repairing work. The main objective of this method is to remove the sharp notch at the crack tip (Fisher et al. (1980) [12]).

Several methods are used for repairing of steel structures. The choice of method depends on the location of fatigue cracking and may depend on the availability of certain skills and tools from local contractors who would perform the repairs (FHWA, 2013 [6]). So, some methods are described below:

SURFACE TREATMENT

The effective and commonly used surface treatment for repairing of steel structures is hammer peening. This treatment is also easiest and least expensive. This can also be used for repair of shallow surface cracks up to 1/8 inch (3mm) deep. And this treatment can also be applied on the welds (FHWA, 2013 [6]). Fig. 3 shows the hammer peening operation for surface treatment.

GRINDING

Grinding is another popular method for repairing of steel structures. This is also used to create a nice finish of the joints or welds of steel structures. It is mainly used to remove portions of a detail containing small cracks at any location of steel structures (FHWA, 2013 [6]).

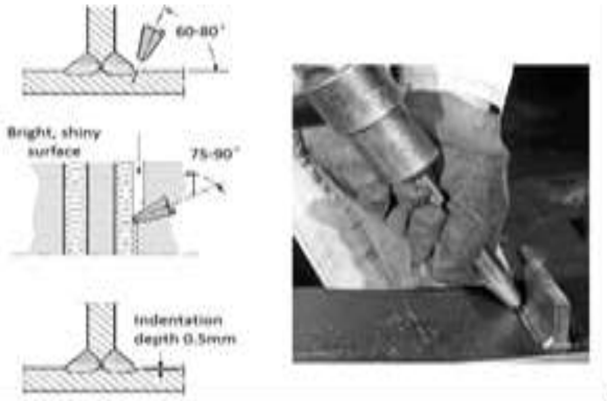

Figure 3: Hammer peening operation [13].

Under cyclic loading, these cracks may turn into fatigue cracks. So, there grinding is needed to repair this (Fisher et al. (1979) [14]). Especially in the field of offshore engineering, structures with tubular joints, where the welds are very large, grinding is effective in shaping the weld and by reducing the associated stress concentration factor, it is enhancing the fatigue strength (Graf, 1977 [15], Yamada et al. (1977) [16] and FHWA, 2013 [6]).

There are two types of grinding. They are: Disc grinding and Burr grinding.

DISC GRINDING

Disc grinding is a circular type of instrument which is an effective means to remove metal. However, if the grinder operation is not careful, too much material may be removed. The goal of the grinding is to remove a small amount of material (FHWA, 2013 [6]).

Figure 3: Disc grinding operation in steel beam (collected from Google images).

BURR GRINDING

The main goal of the Burr grinding is to work in more confined regions than Disc grinding. It is easier to handle and excellent for grinding the edges of welds. However, the cutting rate of Burr grinders 3 ft/hr (1m/hr) is slower than that of grinding wheels, 6ft/hr (2m/hr) (Gregory et al. (1989), [17]). The Burr grinding operation is similar to Disc grinding, However the goal is different, and it needs to be held differently (FHWA, 2013 [6]).

Figure 4: Typical Burr grinder (FHWA, 2013 [6]).

AIR HAMMER PEENING

Air Hammer peening produces the tensile residual stress during the welding process. And this method is simple and effective for weld improvement. And this is commonly used to remove slag from welds (FHWA, 2013 [6]). This type of peening is also useful for improving the fatigue performance of welds without detectable fatigue cracks (Hausammann et al. (1983) [18]). After repair welding, 175% improvement can be done by this (Dexter et al. (2003), [19]). The following picture shows a typical Air Hammer.

IN THE FIELD OF OFFSHORE ENGINEERING

Offshore engineering is one of the most important branches of civil engineering. Offshore structure can protect the coastal area from floods and tsunami. Application of steel becomes popular in the offshore structure day by day. On the contact with sea water, unprotected steel can be corroded. And it is reported that the unprotected steel can be corroded at a rate of about 0.3/year (CDIT, 2009 [20]). And the higher corrosion rate can depend on different locations, structural type, water temperature, wave condition etc. (Zen, 2005 [21] and Xiao C. (2011) [22]) Particularly in japan, 1970s to 1980s building offshore structures were faced great corrosion problem for nearly 40 years (Xiao C. (2011) [22]). Fig. 8 shows two photos, taken in 2009, from the offshore corroded steel pier in japan, which was built in 1971.

Figure 5: Corrosion-damaged pipe piles at an offshore pier (Xiao C. (2011) [22]).

At the time of such construction, if no corrosion protective measure is taken then the design life of such structure will not continue 40 years (Xiao C. (2011) [22]).

OVERCOME

In japan, the cathodic protection and coating protection practice are taken for overcoming such type of corrosion problem. And there also, stainless steel is used in the pipe piles at the splash zone and the tidal zone to protect from seawater corrosion (Xiao C. (2011) [22]). Fig. 9 shows photos of the application of stainless steel to protect seawater corrosion.

Figure 6: Pipe piles covered with stainless steel (Xiao C. (2011) [22]).

To repair the corroded steel structures in seawater, a steel patch welding is a good method for this. They are two types depending on the basis of dry and wet environment. They are dry welding and wet welding. In dry welding process, steel patch plate is welded in a dry chamber condition which is created in under seawater. In this process initial cost is high but maintenance cost is low. And in the wet welding process, wet welds are more susceptible to defects, such as pores, cracks, inclusion etc. Its initial cost is low but maintenance cost is high (Perez-Guerrero et al. (2005) [23] and Xiao C. (2011) [22]). Fig 7 shows the details of steel patch plate welding.

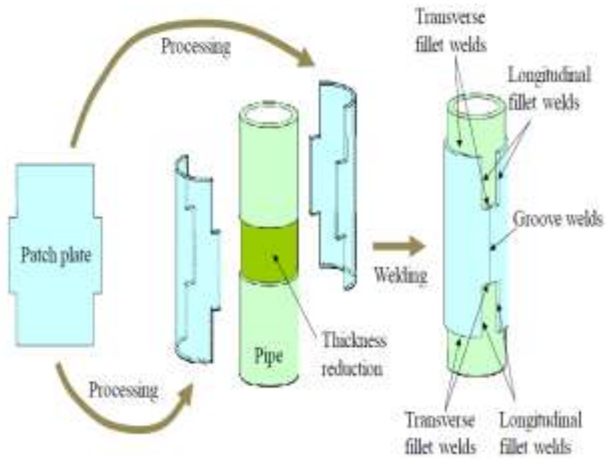

Figure 7: A general procedure of welding patch repair (Xiao C. (2011) [22]).

A paint system which is defined as a coating for carbon steel used in structures is considered as the corrosion protective coating for steel structures. And hot dipped galvanizing is also regarded as a corrosion protection method for steel structures (Xiao C. (2011) [22]).

Using a cover plate at damage steel framed structure is more effective to get strength in the damaged part. Ito T. And Mori K.

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(2016) observed this in the laboratory. Fig.12 shows the repairing method of damaged steel framed structures.

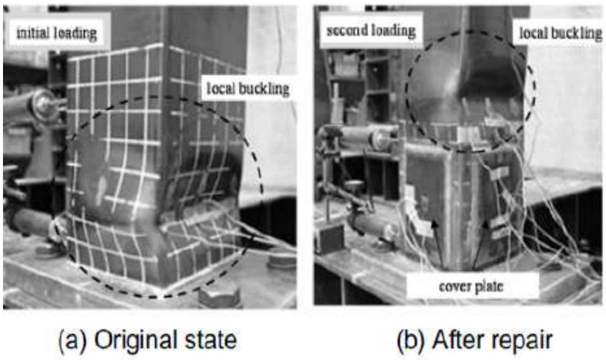

Figure 9: Ultimate state of test specimen (Ito T. And Mori K. (2016) [24]).

Under repair work, certain safety consideration must be followed. So, this is described below:

Safety Considerations: (Way E. et al. (2012) [25])

• Proper Personal Protective Equipment [PPE] must be required. Such as hard hat, safety glasses, steel-toed work boot, safety goggles, fire-retardant clothing etc.

• Care should be taken in the case of the presence of operating equipment, energized electrical wires or cables.

• During facility operation and construction, safe access should be ensured.

• Assessment of corrosion should be done.

During the repairing work, safety must be considered because this is very challenging job. So, during the whole work, proper awareness should be ensured and safety related instruction should be strictly followed.

III. RETROFITTING OF STEEL STRUCTURES

Nowadays a great concerning issue is to retrofit buildings, bridges and other structures seismically as to increase the plastic deformation capacity in the connections of the structures. In 1998, Northbridge Earthquake, many moments resisting structures were failed in connections; from this incident many methods have been applied to retrofit structures seismically (Bertero et al., 1994; AIJ, 1996 [26]).

A proposal was given by (Hayato Asada et al.2014 [27]) to prevent the fracture of beam to column connections, a supplemental H section haunch was added to the main beams for the relocation of the hinge formation and relaxing the beam flange.

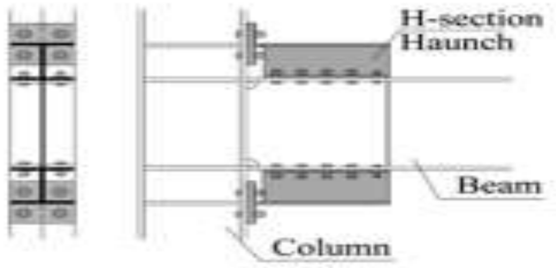

Figure 1. Proposal for seismic retrofit by supplemental H section haunches (Hayato Asada et al.2014 [27]).

To seismically retrofit the steel frames, high-performance fiber-reinforced concrete (HPFRC) can be applied to its higher tensile strength (Kesner and Billington 2005 [29]). This method is used for two panel system , the materials are self consolidated and grade 60 steel is used; two panels are bolted together to act as a fixed-fixed connection with the existing component(Kim et al. 2009 [28]).

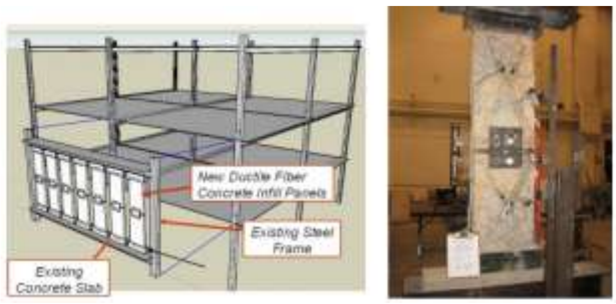

Figure 2. HPFRC infill retrofit system and double infill panel specimen after cyclic testing (Hanson and Billington 2009).

To distribute the vertical force which is generated for the buckling of braces a frame was proposed by (Khatib et al.,1988) is known as zipper frame. Later, Leon and Yang (2003) proposed a suspension zipper frame in which top story frames were designed elastic and all others considered to buckle, such frames were made with inverted v-brace with zipper columns [30].

As a substitute of moment resisting frame a new system was introduced by Christopoulos et al and Collins and Filiatrault (2002a, 2002b,2003) [31] which is known as Self-centering system. This system is a way of limiting the seismic effect economically, also reduces the damage and helps to regain its original shape after the earthquake.

Steel plate shear walls are used in the beam to column connection to prevent the premature failure of column (Xue and Lu ,1994) [32]. The connection of SPSWs is done with bolt or weld in the beam and column joint, the role of this connection is to transfer tension and shear.

Steel truss structures are popular day by and the weakest point in this system is the joint of the member, though this joint is made by bolt, it acts as a weak section. To overcome from this kind of problem energy dissipation devices (Pollino and Bruneau 2003) has been added which can control the wave

And the vibration effect which can increase the strength of load path [33].

IV. STRENGTHENING OF STEEL STRUCTURES

Strengthening is such a kind of method where this is helped to increase the load bearing capacity and update the steel structures. So, in this portion of article, different methods of strengthening are discussed.

By welding additional angle shape profiles, The K type braced frames were strengthened to the diagonal members of this K bracing frame. This strengthening method is increased the cross-section area and reduced the bulking probability of pre-existing K bracing members (Edwin H. et al. (1992) [34]). Fig.14 shows the external and internal frames in N-S direction before strengthening.

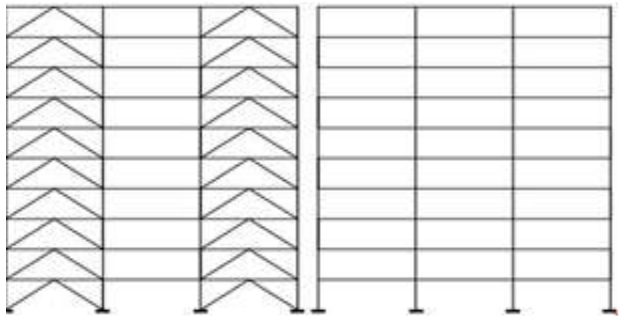

Figure 14: The External and internal frames in N-S direction before strengthening (Bazaz B.J. (2000) [3]).

Fig. 15 shows the external and internal frames in N-S direction after strengthening.

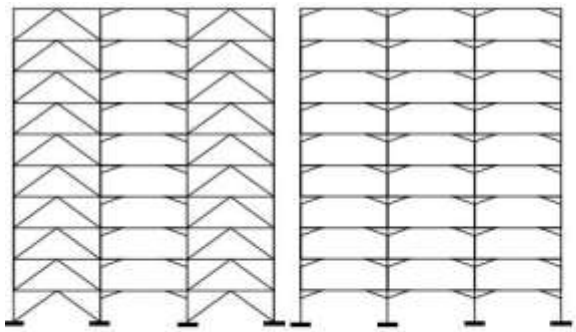

Figure 15: The External and internal frames in N-S direction after strengthening (Bazaz B.J. (2000) [3]).

Another method of strengthening and updating of the steel structure is to create beam-column joint between existing beam and existing column. It helps to increase the loading capacity of steel structure (Hick J.G. (1987) [35]).

Welding additional plates on both sides of existing columns is used for strengthening. This technique has helped to increase the load bearing capacity of steel column (Khalifa A. (1999) [36]).

A mat foundation is considered as a large concrete slab is to carry many columns in several lines with base soil. At the type of low bearing capacity of base soil and higher column loads, then the mat foundation is suggested. It may go excessive settlement because of this reason. So, strengthening is required for this. According to this, Anchorage bars are used to increase the strengthening of this mat foundation (Khalifa A. (1999) [36]).

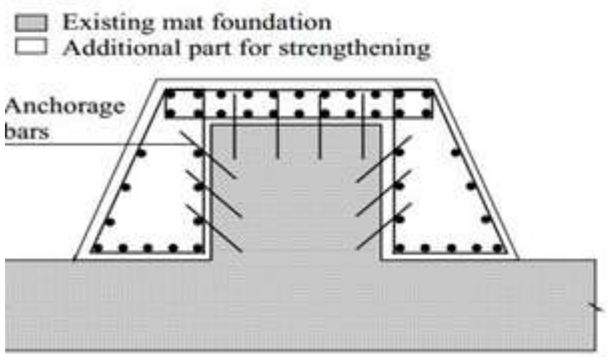

Figure 19: A schematic representation of mat foundation strengthening (Bazaz B.J. (2000) [3]).

Narmashiri K. et al. (2001) showed his paper that the strengthening of steel I-beams can be improved by using carbon fibre reinforced polymer (CFRP). And he used ANSYS software in the three dimensional (3D) modeling case and nonlinear static analysis. And he also showed the results that different types and thickness of CFRP plates influenced the load capacities and strain distributions properties of this. Fig. 20 shows the 3D simulated specimen of I-beam according to that results (Narmashiri K. et al. (2001) [37]).

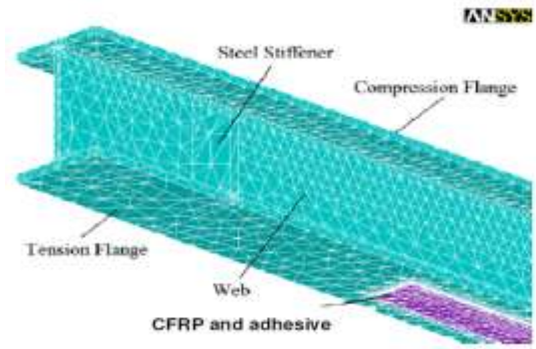

Figure 20: 3D simulated specimen (Narmashiri K. et al. (2001) [37]).

Using stiffener is also a popular and most effective method to improve the strengthening and bearing capacity of steel. Fig. 21 shows the details of using stiffener in steel beam or column.

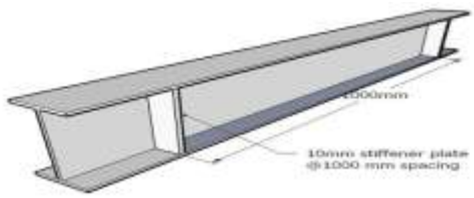

Figure 21: Details of using stiffener in steel beam or column [38].

Now a day, concentric and eccentric bracing systems are also considered as a good strengthening technique.

V. RESEARCH GAPS AND FUTURE RECOMMENDATION

1. More investigations are required to execute the grinding operation in the field of offshore engineering.

2. Specific differentiation should be done between the disc grinding and burr grinding. And their suitability should be specified.

3. More researches should be needed in the dry welding process of offshore engineering.

4. Additional investigations are needed on the basis of foundation strengthening.

5. Further investigation should be needed on the basis of some specific improving materials to improve the bearing capacity of I-beam such as carbon fiber reinforced polymer.

VI. CONCLUSIONS

1. Burr grinding is to work in more confined regions than disc grinding and burr grinding and burr grinding is easier to handle and having an excellent grinding operation.

2. The air hammer peening method is simple and effective for weld improvement.

3. Using stainless steel in pipe piles is the solution of protecting corrosion in the field of offshore engineering.

4. Strengthening of steel I-beams can be improved by using fiber reinforced polymer (CFRP).

5. Using stiffener is also a popular and most effective method to improve the strengthening and bearing capacity of steel beams or columns.

6. Higher research must be needed in this field to overcome the high intensity of seismic activity. This past records will help to find out a newer one which would be more economical and stable.

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