Strengthening of Steel Frame Connection and Finite Element Analysis

Results

ADRIAN IVAN, MARIN IVAN, IOAN BOTH
Department of Steel Structures and Structural Mechanics
University “Politehnica” of Timisoara
Str. Ioan Curea, nr. 1, cam.14, Timisoara
ROMANIA
adrian.ivan@ct.upt.ro, marin.ivan@ct.upt.ro, ioan.bot@ct.upt.ro

Abstract: This paper presents the analysis of a steel connection. The analysis is performed using solid finite element and is compared to the experimental test performed in the laboratory. During the analysis special attention should be paid to the deformed shape revealed by the finite element analysis which also shows the distribution of stresses in the elements.

Key-Words: deformed shape, strengthen, strain gauge, boundary conditions, stresses.

1 Introduction

Steel structures are used in different fields of civil engineering as: roofs, halls for production, exhibition halls, towers for radio and TV transmission, pipes, bridges, foot bridges, high-rise buildings.

Maintenance, repair and strengthening of existing steel structures are important activities for civil engineers. Many experts and consulting engineering firms are concerned with analysis of existing steel structures and the design and execution of repair and strengthening measures.

Steel structures are found in the world in many fields. A part of these steel structures are near the end of their service life. Processes of the deterioration are the result of steel corrosion, deficiency and inclusions in welding, cracks in the welding, buckling of elements and local deformations of elements, defects in micro structure of steel which have generated by different causes.

The deterioration processes, their causes and the counter-measures to remove, reduce or retard their actions, the methods to repair the damage that they caused, have been frequently analyzed for steel structures and steel bridges.

Repair measures aim to re–establish a structure’s capability to accept the actions for which it was designed with sufficient safety and durability. Repair measures can usefully extend the service life for deteriorated steel structures. The need of repair may also arise due to errors in design, construction and maintenance, or due to accidental damage.

The usual aim of strengthening of existing steel structures is to allow for increased actions. The need to strengthen a structure may also impose higher functional requirements than those anticipated in the original design. Steel structure should be replaced only when it has been established that repair or strengthening measures are not technically feasible or economically reasonable.

2 Diagnostic of steel structures

Actual procedure for diagnostic of steel structures is obtained by long experience in reconstruction and monitoring technical conditions, making diagnosing activities systematic, unifying methodology of diagnostics and informing on necessary equipment by instruments. It assumes gathering of continuous documentation about the structure as a background for proposing of a way for reconstruction.

Existing steel structures can be affected by different (various) deteriorations. Repair interventions can vary considerably in scope. Minor interventions should be undertaken during routine maintenance. Structures must be cleaned regularly of mud, weeds, debris, salt and other aggressive substances. The aggressive substances can initiate the progressive deterioration of steel structures. Drainage systems must be regularly cleaned and repaired.

Repairing of small deterioration due to corrosion is common for steel structures. In these cases surface layer or paint cover is thin and steel has no protection.

When more complicated repairs are made to an area of major damage the process is called rehabilitation. Replacement of corroded bars is such a rehabilitation repair. The replacement bars are welded to bound existing bars. It should be noted that, during performing of this type of repair, the structure may need to be temporarily supported.
Cracks in the weld should be backfilled by additionally injected weld, which increases the durability of the structure. The repair can be controlled by ultrasonic devices and by coring.

Before a decision to strengthen is made, the remaining capacity of structure should be determined. After technical expertise, alternative measures to increase the capacity of structure should be considered. Strengthening is usually the most serious intervention. When the live load is small in comparison with total actions, after strengthening additional live load can be supported. This is the case when the dead load is relatively high, as is typical for concrete structures. The safety condition of structure can be written as the effects of actions typical for concrete structures. The safety condition of structure can be written as the effects of actions Sd should not exceed the corresponding design values of structure’s resistance Rd.

\[ S_d \leq R_d \]  

If the effects of actions on the structure were to exceed Sd, the structure will need to be strengthened accordingly.

Strategies for strengthening existing structures can be classified into two groups.

The first group consists of strengthening methods which will increase live load without increasing resistance. Increasing live load does not call for increasing the design values for actions’ effects, Sd. Without any increase in the resistance of the structure, Rd remains adequate. This can be achieved by decreasing dead load. This method is frequently applied, as it does not involve the complexities of an actual strengthening intervention in the full sense of the word. Decreases the dead load can be achieved in the buildings by replacing existing heavy floors and walls with lighter elements, or for bridges, by replacing heavy pavements with lighter ones. Reduction of dead load is often applied when additional stories are built on existing structures. In such cases, the additional dead load of the new construction should be taken into account. It should also be noted that, due to the greater partial safety factors required for live load than dead load, the additional live load is less than the removed dead load.

Decreasing the span of existing structure is possible to allow an increase in live load that will be sustained by new supports. This method is applied when overall dimensions and aesthetics allow. Decreasing a span can be achieved by expansion of supports.

Changing the structural system is highly versatile. Using a new supplementary structure is possible to have a higher capacity of existing structure.

Additional pre-stressing is an efficient way of strengthening of structures. When additional pre-stressing is applied, the stresses in existing structures should be precisely known. Care should be taken that tendons (ties) are sufficiently tensioned and corrosion will not develop.

The second group of strengthening measures consists of those which increase the design values of resistance of structure Rd.

Increasing the cross section is a simple and frequently applied strengthening method; Additional elements on the cross transversal section of elements is a very efficient method of strengthening.

Additional reinforcement in the tension zone is a very efficient method of strengthening. Strengthening of circular cells in a steel silo has been successfully performed by adding reinforcement which has been protected with steel on outside of the silo.

Additional bonded steel plates are good strengthening measures that have grown widely in recent times. Bond between the additional steel plate and the existing steel structure can be successfully achieved by welding or bolting. Instead of steel plates, other materials can be used. Bonded carbon-fiber or reinforced plastic plates have been used successively for this purpose.

Replacing structural members refers to strengthening of a steel structure by replacing structural members or by adding new members without removing existing ones. A convenient solution for strengthening a steel structure is to replace the existing deck. The new deck has been bonded to the existing girders by anchors and sealed with weld or with epoxy mortar.

A footbridge with a suspended deck has been strengthened by new steel hangers, without removing the existing pressed ones.

3 Description of the experiment
All these measures are considered due to a rational thinking and an engineering point of view. But, these measures need to be analyzed and simulated numerically and tested in the laboratory. The present paper makes a comparison between the results obtained in the laboratory and the analysis using finite element method.

First, it was tested a welded beam to column connection as shown in Fig. 1. The force was applied normal to the column. The strain gauges gave the results for each step of 100kN. The final value of force P was 2000kN in order to avoid yielding in the
assembly. This was necessary because the second test would have been performed on the same sample and the plastic deformations would have given inaccurate results.

The parts of the experimental connection are presented in Table 1.

<table>
<thead>
<tr>
<th>Part</th>
<th>Cross-section</th>
<th>Length [mm]</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0-</td>
<td>-1-</td>
<td>-2-</td>
<td>-3-</td>
</tr>
<tr>
<td>P001</td>
<td>HEB300</td>
<td>1300</td>
<td>OL52 (S355)</td>
</tr>
<tr>
<td>P002</td>
<td>HEB300</td>
<td>150</td>
<td>OL52 (S355)</td>
</tr>
<tr>
<td>P003</td>
<td>Pb140x10</td>
<td>240</td>
<td>OL52 (S355)</td>
</tr>
<tr>
<td>P004</td>
<td>Pb100x10</td>
<td>100</td>
<td>OL52 (S355)</td>
</tr>
<tr>
<td>P005</td>
<td>Pb300x25</td>
<td>300</td>
<td>OL52 (S355)</td>
</tr>
<tr>
<td>P006</td>
<td>Pb240x10</td>
<td>1300</td>
<td>OL52 (S355)</td>
</tr>
<tr>
<td>P007</td>
<td>Pb240x10</td>
<td>460</td>
<td>OL52 (S355)</td>
</tr>
</tbody>
</table>

The strengthened experimental model is presented in Fig.2. The difference between the two models is the plates welded on the exterior of each flange denoted P006 and P007, in Table 1.

The strain gauges were put on the model as follows: two on the beam’s web, two on each of the beam’s flange, two on the column’s web for the strains developed normal to the force’s direction, two on the column’s web for the principal directions and one for strain in the direction of the force and there are three more strain gauges placed on one of the columns flange for the strain normal to the force’s direction. A sketch of the gauges placement is shown in Fig.3.

The main aim is to use the finite element method to observe if the results obtained in practice are the same with the ones simulated with computer programs. The advantage of such comparisons is the fact that, for the future, there is not necessary to spend money on experimental tests (unless necessary).

For the simulated analysis, the models were created as solids like in Fig.4.

The finite elements were chosen to be arranged in the mesh as structured elements, but, at the intersection of an element’s web with the flange, there cannot be discretized only with tetrahedron elements. This happened because the cross-section of the profile was modeled with the profile’s radius between the web and the flange and not by plate joining. Because the part between the straight flange and the straight web was limited by three surfaces the meshing resulted with much more distorted elements. For this reason the entire profile was meshed using tetrahedron elements.

The boundary conditions were defined on surfaces, reducing first the translations on the vertical direction. The analysis did not reach a final analysis so the boundary conditions were changed. The displacement was reduced on both horizontal directions. The error might have occurred because this non structural mesh is not symmetrically with respect to all three axes. The bond between the elements was considered to be “tie”. The application
of force was similar to the one applied in reality, a circular surface of 15cm diameter.

In Fig.5, the deformed shape of the first model (un-strengthened) also shows the stresses in longitudinal direction of the column. Red represents the tension and blue means compression. Fig.6 shows the same stress at the same force applied on the plate. Also the color representation is the same as mentioned before.

From the two figures it can be seen that the models have the same behavior but the areas where the stress was maximum, are now smaller or gone, meaning that the connection can still be loaded until it reaches the yielding point. Another thing that can result from the analysis is the fact that, although the strengthening parts on the upper flange of the column are not continuous, there is no stress concentration in the nearby of the welding between the column and the beam.

In the first situation, the location where the stresses have high values, are represented by small areas. These locations are: the supports of the model, the corresponding zones but on the other flange, the vicinity of stiffeners.

In the second case, the areas, with close values for the stress, are larger meaning that the distribution of stress is more uniform and the location of yielding stress can be seen only in the support surfaces. The circular surface has also yielding points because the bending of the column had an influence on the bending of the plate welded to the beam. The same print could be seen on the experimental specimen, where the force was distributed finally through two areas apart from each other due to the detachment of the center of the plate from the pressure cylinder.

Mainly, the stresses in the strengthened elements are less than for the first case, as it can be seen in the charts in Fig.7 and Fig.8. The rhombic filled line represents the values for the un-strengthened model and the triangle filled line represents the model with consolidation plates.

Fig.7 and Fig.8 show the stress of gauges 8 and 9 which are positioned on the lower flange of the column. Here, the stresses are reduced by 25-40%.

Most of the gauges present the same behavior but as the stresses needed to be distributed to the supports, there are locations where the stresses exceeded the values obtained in the first analysis model. A special attention should be paid to these
zones as they can reach the yielding point before other main parts of the element.

Fig.9 shows the values obtained in the location of gauge 16, placed on the web of the column. It can be seen that the stresses in the case of un-strengthened model are less than the values obtained in the second case. It results that the web of the column is more stressed, but the values are not very high.

![Gauge 16](image)

**Fig.9 Results for gauge 16**

## 4 Conclusion

The repair and strengthening of steel structures have become increasingly important in civil engineering tasks. The steel structures are durable, they do deteriorate significantly over time and to extend their service life, they must be repaired. Repair measures enable the deteriorated steel structures once again to sustain the action defined in their original designs. Strengthening allows the designed actions to be increased. Both types of measures should be fully explored before demolition and/or replacement by new structure.

The results for this finite element analysis were very close to the results in laboratory. This is very important to know since, for the future, the need of experimental tests will be smaller, for certain modifications in the features of a steel frame connection.

The finite element analysis shows the deformed shape of the connection and can give a more accurate location of the affected zones. Results show that, although there is a rigidity loop on the column, the stresses do not exceed the yielding point in that area. This doesn’t mean that the connection is well designed since the over-strength coefficient has to be taken into account when a design for seismic action is performed.

Another idea resulted from this analysis, is the one that attention should be directed to other effects of the action. Here, although the stresses in the flanges decreased, the stresses in the web of the column increased, for the same acting force.

**References:**