Fabrication and Construction of Steel Structures in Turkey, Common Errors and Remedies

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Abstract: Steel structures are becoming more preferable in Turkey due to their rapid fabrication and assembly, the increase in construction quality and the decrease in the construction costs. A steel structure is constructed in three main phases: planning, fabrication and assembly. An economically constructed high quality steel structure can only be possible if the mentioned phases are successfully completed without errors and problems. In order to achieve this purpose, a certain level of overall knowledge and experience in the construction phases are required. In this work, technical knowledge and experience gained in steel industry are put together to explain some of the important technical issues in planning, fabrication and assembly phases of steel structures in Turkey. In addition, common problems and their remedies are presented through examples.

Key-Words: Steel structure, project, planning, fabrication, assembly, construction, application error

1 Introduction
Most regions of Turkey are prone to earthquakes. Earthquakes, especially the ones occurred in the last 15 years have caused catastrophic damages. In order to prevent the similar results of the inevitable future earthquakes, steel may be preferred over concrete as a material due to its superior properties such as high strength, low weight, higher elastic range and easier and better control of fabrication.

A light structure is less affected by earthquakes and allows small foundation dimensions. Taller and longer span structures can be built by steel, even on grounds with low carrying capacity. Steel structures are generally lighter than concrete structures and thus, earthquake effects acting on the structure are smaller. Much longer spanned structures with smaller cross sections can be built using steel than using concrete. Larger structures made with steel can be built on low carrying capacity ground. Moreover, steel structures can be built in all weather conditions and within a short construction period. Despite these superior features of steel structures, if the required care and attention are not paid in the planning, manufacturing and assembly phases, large losses might occur in the construction cost and functionality.

2. Planning, Construction and Assembly Phases, Common Errors and Remedies

2.1 Planning Phase of Steel Structures
The project planner should precisely determine the location of the construction area, the supports and joints based on the existing conditions, and the column spans in the most economic, functional, as well as statically feasible ways [1].

The most common planning mistake is getting joint solutions incompatible with the fabrication or assembly conditions e.g. planning a hinge joint at a location where a fixed joint is more easily constructed. This decision in turn will affect the
static behavior of the structure. Fabrication detailing should always be considered when planning the structure.

Engineers may prefer doing hand calculations of the purlins then transferring the calculated forces onto trusses. These forces are applied only to trusses and sometimes as distributed loads. This methodology causes incorrect moment values on trusses. In reality they must be applied as point loads in order to reach reliable static solutions.

Wind loads are determined based on building height and spans. When applying them to the structures, their effect (positive pressure or suction) must be determined correctly. Wind loads cause positive pressure effect on the columns where the loads act directly, and suction effect occurs on the opposite side columns. However, this is different for trusses. Depending on the truss member inclination, there may be pressure or suction effect on the wind load application side. If the inclination of the truss member is small (inclined at an angle less than 25 degrees), it will be under suction effect, otherwise it will be under pressure effect. Suction effect loading is applied away from structure and pressure effect loading is applied towards the structure. It is likely to do mistake when applying pressure-suction effects. On the side where the wind load is applied indirectly, the effect is always suction. As seen in Fig. 1, due to the small inclination of the roof on the wind loading side, the loading type is suction. On the other side, the effect is again suction, as given in TSE 498. It should be kept in mind that the members on which wind act indirectly are always under suction.

Another common mistake is made in modeling purlin and truss connections. If the purlins will be connected to trusses rigidly, then the model should be consistent with it and the manufacturing process must be performed accordingly (Fig. 2). An engineer should be well informed about steel connection properties and should model consistent with the design.

Earthquake and wind cross bracings have hinged connections (Fig. 3). Their connection types are usually ignored, in turn, static problems occur.

When designing structures with cranes, they are usually analyzed separately. The computed vertical reaction forces from the crane supports are then transferred to the cantilever beams of the columns in the main model. The effect of moving loads, braking effect and twisting effects on the cantilever beams and the moment about weak axis of columns when the crane beam is positioned in between columns, are usually disregarded (Fig. 4). These effects should be considered by applying the related support reactions. Alternatively, the crane beam can be regarded as a bridge and the crane loading as a vehicle in the analysis (Fig. 5). The latter way is difficult to do and is not usually preferred.
The connections will be designed using the forces and moments obtained from static modeling. Connection detailing should follow the provisioned connection type, which is either fixed or hinged (Figs. 6-7). When designing the steel connections, all of the forces and moments obtained from the model should be transferred to and placed on the connections. A possible error can be done is to detail a connection as hinged although it was modeled as fixed in the computer model, or vice versa. This error may lead to catastrophic problems in the behavior of the structure.

After the analyses, the structural drawings are prepared strictly following the static calculations. The drawings should be neat, clear and comprehensible. Most common error in the drawings is to transfer the analyzed model incorrectly to the connection detail. The drawings should always be verified by comparing with the models analyzed.

Analysis and drawings against the enforced codes will result in lawful liabilities, and engineers should be very well aware of this. Earthquake effects will become larger for higher risk regions and as the number of stories increase. Project developers must not avoid applying all required loads as required by the codes in order to lower the construction costs illegally. The projects should meet all general anticipations: strength, functionality, speedy and easy construction, economy as well as aesthetics.

2.2 Fabrication Phase of Steel Structures

After completing the project phase of the steel structure, the fabrication phase starts using the drawings showing all the details of all members or the 3D model of steel structure obtained from the software package. A list of members showing their count and manufacturing order is prepared after obtaining the 3D drawings of the steel structure being built (Figs. 8-9). The number of members can be obtained from the software package, however this information should be double-checked and verified on the drawings. The fabrication drawings should also be verified by the drawing team. This phase is very important since the number of members in a steel structure is very high and a mistake in calculating it will be very costly and time consuming.
The steel members are exposed to sanding, spot-welding and construction processes after their fabrication. An example of this construction process is the preparation of the column parts for welding process. This is done by an experienced team under the supervision of a technical person. The parts to be connected should be carefully and correctly positioned on each other by precise measurements. The required measurements are handed out by technical personnel. The measurements are obtained from the software package and should be double checked using shop drawings of the members. The most common mistake made during construction is to spot weld parts on wrong locations. It can be due to wrong measurement data given by technical personnel or can be the mistake of fabricator. The technical person should not only give the location of the part to be spot welded on the main member, but also verify the position by taking an extra measurement from a different edge. Wrong fabrication is usually noticed in the construction site and correcting the fault will be costly and time consuming.

Construction process in the fabrication shop is shown in Fig. 10. In the figure, the drilled parts ready to be connected by bolts in the construction site are also shown. If their position is not precisely correct, the parts cannot be bolted together in the construction site. The person in charge of construction process takes a lot of measurements and is likely to make mistakes. Therefore the necessary verification mechanisms should be established. Measurements should always be verified by extra measurements taken from different points. Having more than one person in charge of verification will reduce the risk of making mistakes. The parts which are spot welded and made ready for connection welding should be rechecked by a different technical person.

Spot welding should be done in a way that spot welded parts should not separate during transportation. Moreover, it should not prohibit the continuity of the connection welding. If the spot welds are smaller than necessary, separation might occur and if they are larger than required, they can block the way of connection welding. Spot welders should be informed about these issues.

After the spot welding process completed, the manufactured parts are welded together (Figs. 11-12). Before welding, the parts should be checked by a technical person in charge of construction. All parts to be welded, especially the spot welded locations should be cleaned by a wire brush. Dirt and residue on the welding surfaces adversely affects the quality of the weld. Welding should be continuous and applied to the whole welding region at once. If this is impossible, the welding should be overlapped to where it was left off. It should be checked if the welding thickness requirement of the project is conformed. The locations where the requirement is not conformed should be reinforced by additional welding. Welding is one of the most
important processes that can provide connection between steel structural members and behavior as stated by the project.

![Fig. 11. Parts ready for welding](image1)

![Fig. 12. A column with welding job completed.](image2)

The welding should always be performed after placing the welding surface in horizontal position as much as possible. It should be avoided to weld in vertical direction. The best results are achieved by horizontal welding. Therefore, the member to be welded should be rotated four times in its axis to weld all faces separately.

Another important issue when welding is workplace safety and health. Welder should take every precaution necessary. Helmets, goggles or safety glasses, gloves and special clothes for welders should always be worn, and no one should be allowed welding without wearing them to avoid injuries during welding such as being struck by flying particles and chipped slag, being exposed to ultraviolet radiation and having radiation burns, and irritation and chemical burns from fumes and chemicals.

When the welding process is done, the responsible technical person should check the structural members welded. If there are any defects, they should be corrected. After completing the checks, painting process can start which is the last process for the members before installation, and the last phase to identify any possible problems (Fig. 13). The error tolerance between steel parts is 2mm. If this tolerance cannot be achieved, the parts cannot be installed at the site. During the painting job all necessary precautions to prevent health problems must be taken. Inhaling paint can be poisonous and workers should wear gas mask during paint job. The workplace should be well ventilated.

![Fig. 13. Painted steel members](image3)

Protective paint cover thickness varies according to the installation location of the members. This thickness is defined in microns in the project. The thickness requirement should be satisfied. A technical person should measure it by a thickness measurement device. If the requirement is not met, either the painting job is repeated or local corrections are made.

The welded members are sometimes galvanized instead of being painted. Galvanization is to apply protective zinc coating to steel members to prevent rust. This can be done by hot-dip galvanization where the steel members are submerged into a bath of molten zinc or by electrochemical methods. If steel members to be galvanized have closed regions, they should be drilled so that the molten zinc can come out of the holes. The member surfaces should be fabricated in a way to allow easy contact with zinc (Fig. 14).

![Fig. 14. Galvanized steel members](image4)
Manufacturing phase of steel members is the longest phase in building a steel structure. The fabrication period directly affects the total building time. A fault free fabrication allows the steel structure to be assembled in a short time. Otherwise, the parts fabricated with faults should be transported back to the fabrication shop and should be repaired or refabricated. In the meantime, the construction should wait for the parts to be corrected, in other words, assembly will stop. To prevent such time losses, a well control mechanism should be established in the production phase. Hiring experienced steel workers in the fabrication shop will prevent most of the problems. It should also be kept in mind that fabrication errors may cause significant financial losses.

2.3 Assembly Phase of Steel Structures

The assembly phase of a steel structure might be initiated when the fabrication of steel members is fully or partially complete. For example, the fabrication of columns may be complete while the remaining steel members are still being fabricated. Then the assembly of the columns can start in the construction site. During column assembly, the remaining steel members can be transported to the site for subsequent assembly.

Before the assembly starts, the construction site is arranged, safety precautions are taken and assembly project is prepared. Column bases manufactured previously for column assembly are checked. Column base axes should be fixed within 3-4 mm tolerance (Fig. 15). Otherwise, columns axes will be incorrect and beam installation will not be possible. The angles between intercrossing column axes should be precise to allow installation of the steel members.

As is seen in Fig. 15, the column bases are attached to the column footings and they await concrete to be poured. The distances between column bases are measured using a tape measure, the angles between column axes are geometrically set (right triangle method) and the elevations are adjusted using a nivo. Mistakes in elevations, angles of intercrossing axes and distances between column axes adversely affect the assembly of the earthquake cross bracings, wind cross bracings, and beams, respectively. These mistakes may sometimes make the assembly impossible. Therefore, the column base plate application should be very carefully done with multiple repetitive measurements. Sometimes, even column bases are perfectly installed; shaking due to casting of concrete may cause them to slide. In order to prevent this problem, anchorages of column bases should be fixed to the column footing reinforcement by steel plates. After doing this, the anchorage region above the column footing should be preserved (Fig. 16) otherwise, the concrete pouring process will harm the anchorage threads and the bolts will not fit well during column assembly.

Fig. 15. Application of column footings

In the assembly process, the steel columns are tied to the crane by a polyester rope safely. It should be made sure that the crane and rope will safely carry the weight of the column. There should not be any people or vehicle under the columns during their erection by cranes. The columns are aligned to the desired position over the base plates and are then placed on the plate’s surface. The bolts should be tightened enough to prevent slips under heavy weather conditions. The corner bolts should be tightened at least. Depending on the size of the base plate, the mid-edge bolts might need to be tightened as well. The crane rope should never be untied until before completely fixing the columns to the bases.
During the assembly, workers may prefer to climb high locations using the crane rope in order to finish the job faster. This will jeopardize their lives and must not be permitted at all (Fig. 17). Workers, even with their own will, must not be permitted to do any action that will risk the workplace safety. Unfortunately this type of behavior may be encountered in construction sites. Technical personnel on the site will be held responsible for any workplace accidents.

![Worker’s dangerous activity using crane rope during assembly](image1)

Fig. 17. Worker’s dangerous activity using crane rope during assembly

As it is seen in Fig. 18, workers may not take required safety precautions, especially in Turkey. Alternative ways to lift workers to higher locations safely should be offered to prevent this kind of unsafe actions. Lift buckets designed for crane booms can be used for safe, easy and fast assembly.

![Workers at a high location without a safety belt](image2)

Fig. 18. Workers at a high location without a safety belt

Especially when doing beam assembly, the workers must wear all necessary safety accessories. No worker must be allowed without taking safety precautions.

After installing columns, assembly of beams and other parts may take turn. In the assembly project, the size, location, orientation and position numbers of the steel members are all mentioned. Wrong bolts may be used during assembly. This causes insufficient bolt dimensions for connections and should be prevented by double-checking the diameters and lengths of the bolts with the project before installation.

In the assembly process, so many bolts are tightened and no bolt should be left untightened by mistake. Forgetting to tighten a bolt means the connections and in turn, the structure as a whole will be statically weaker than it was designed. In order to prevent this, after bolts are tightened by a worker, another worker should verify their tightness.

Due to lack of detailing in the project, construction of column anchorages may be necessary during the assembly phase. They are implanted into the concrete by drilling holes and gluing with epoxy. The process is hard to perform and requires a lot of care. The strength and reinforcement amount of concrete plays an important role in the process. Tight reinforcement may not allow drilling anchorage holes into required depths. Then, using core drillers, which can also cut the reinforcement, may be necessary. Anchorage implantation with insufficient adherence will cause serious static problems such as bond slip and concrete failure (Fig. 19). Correction of this failure problem will take a long time to fix and it will be costly.
3. Conclusion

In the structural plans, fabrication measurements of all members of the structural system, the qualities of the steel to be used and the list of connection parts required for assembly and their qualities should be presented. Moreover, the technical specifications booklet should be prepared along with the plans and the contractors should strictly follow the instructions given in the technical documents. In these documents, the essentials of fabrication and assembly, qualities and application instructions of the paint and quality testing procedures should be given in detail.

Connection details of nonstructural members to the structural system should be available in architectural plans. Based on these details, the connection parts to be placed on the structural system should be shown in static plans so that they can be manufactured in the fabrication shop. Similarly, the details necessary for the application of mechanical job and electrical wiring should be planned during the planning phase.

In the plans, the materials to be used should be defined properly, application details should be included and connection details should be shown. Fabrication should be carried out following the plans and codes in the fabrication shop and welding job should be performed by certified welders.

In steel construction, it is essential that all fabrication be done within the fabrication shop. In the construction site, only assembly is to be carried out. Welding in the construction site should be avoided except it is completely necessary. In Turkey, unfortunately, fabrication of welded connections in the construction site is commonly considered as an assembly job. However, welding job performed in the construction site should be considered a fabrication not an assembly.

Before starting the assembly job, an assembly project showing the members and their fixing locations, the way they are going to be fixed, the fixtures to be used and member transportation details, must be prepared. The assembly team is then informed about the assembly project. The members are transported and laid out in the construction site according to their assembly locations.

Project is the main factor affecting the construction speed and easiness. The second important factor is fabrication. In steel construction, project, fabrication and assembly phases affects one another in the order they are written and they are like the rings of a chain. A weak ring will cause problems to the others. Two statically similar structures may be completed in very different time periods due to different approaches in project, fabrication and assembly.

In summary, a certain level of knowledge and experience is required in every phase of steel construction. The fabrication and assembly phases should be planned in the easiest and fastest way following the static plans. The advantages of steel construction should be benefited to the best extend and the methods for completing the maximum job in the minimum time should always be studied.

References: