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The maintenance of historic iron and steel structures: repair techniques

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Abstract

When historic structures require restoring or renovating, the question arises of whether damaged or broken elements can or should be repaired.

The restoration techniques are directly linked to both the types of material used and the question of whether the intention is to simply to restore the appearance of the structure or to ensure that actual forces can be accommodated. The paper will indicate the techniques that can be considered for use on cast iron, wrought iron and other types of steel. If it is necessary to replace elements attention will also be paid to the availability of historic types of iron and steel and to when modern materials must be used. Historic and modern methods of constructing joints will also be considered.

Many old structures are important for historical or cultural reasons. When restoring such structures it is necessary to decide whether to allow the fact that restoration has taken place to be obvious, or whether the original appearance should be maintained in order to show how structures were previously constructed.

1. Introduction

Corrosion, overloading, collisions and other calamities may damage old structures. When they are restored this must be done in such a way that their original appearance is retained and that they are able to bear the loads that are imposed upon them. The method used to accomplish these aims will depend on the historic and cultural value of the structure and the available financial resources.

When a structure that has a high value is only slightly damaged it is usually possible to return it to its original condition and thus to retain a consistent appearance and to show how it was constructed. However, when the damage is more serious some elements will have to be replaced. Depending on the historic and cultural value and the financial means, either the original materials and construction methods will be used or it will be necessary to resort to the use of

modern materials and modes of connection. In the latter case the appearance will be retained but the modifications will be visible to an experienced eye. When much of the original material has to be replaced an interesting blend of old and new may be created in which honestly shows which parts are original and which are new. The new construction must blend with the old with regard to size, scale and appearance. This paper considers the repair of cracks and fractures, the replacement of corroded material and the application of strengthening measures. After this the availability of historic materials and connecting techniques is considered.

Distinctions must be made between cast iron, wrought iron and old types of steel. Cast iron is a material with a high permissible compression strength but a low permissible tensile strength and moreover it is brittle. Wrought iron can take up both compression and tension and can be cold forged. Because of these big differences in their properties, the repair techniques used for these materials also differ. Older types of steel are similar to wrought iron but the differences in their material properties also result in the use of different repair techniques.

2 Repair techniques used for cast iron

The most important methods of repair are welding, using dowels, metal stitching and using adhesives. The degree to which forces can be transferred depends on the method used.

2.1 Welding

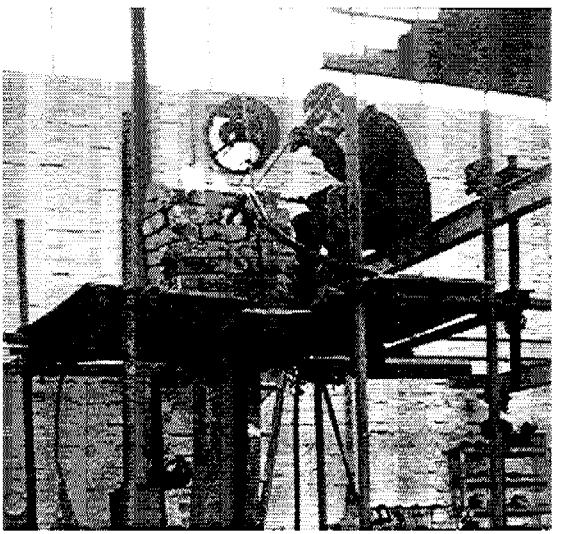

Figure 1: The welding of cast iron in an improvised furnace on site. The repair of cast iron gutters, Palm House, Kew.

Owing to the high carbon content it is difficult although not impossible to weld cast iron. This method requires great skill. A distinction must be made between hot and cold-welding. With hot welding the cast iron must be slowly preheated up to 450^0C –600^0C. An electrode with a cast iron or carbon rich steel core must be used for the welding and to avoid stresses the welded element must be allowed to cool slowly. The bigger the cast iron element, the more difficult it is to weld it. Preferably the preheating must be done in a furnace but it may also be done in situ.

For cold welding the cast iron element is either cold or only slightly preheated. The electrode used must have a different composition from that of the parent material and is usually rich in nickel. The weld must be able to withstand a relatively high strain during cooling. After preparation the opening is closed by short strips of welding. Overheating must be avoided and the weld must cool slowly.

Hot welding usually provides a stronger connection than cold welding. However, for both methods it is better to consider a welding to be a means of adhesion rather than a connection that can transfer strong forces. It is always wise to assess the suitability of the materials for welding in the laboratory before using this method.

2.2 Dowels

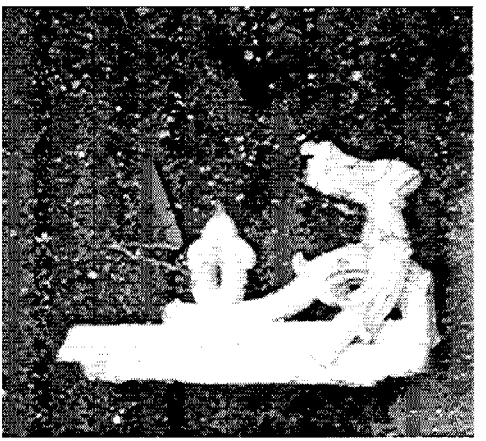

Figure 2: The repair of decorative cast iron elements by means of dowels, Palm House, Kew.

The repair of parts that do not need to bear any forces, such as decorative elements, can be carried out by simply using dowels. These are glued into holes drilled on each side and thus the link is restored. It is also possible to drive tap-bolts into each part and then to weld these to each other, in which case it is easy to determine the strength of the connection.

Metal stitching

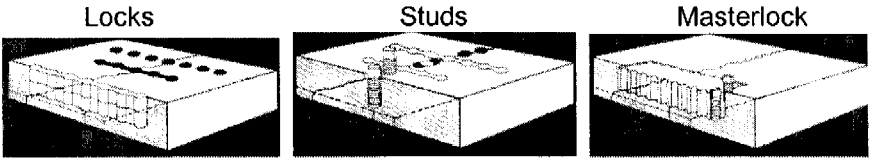

Figure 3: The repair of cast iron by means of metal stitching. Locks are placed at right angles to the crack. The crack itself is closed by means of studs.

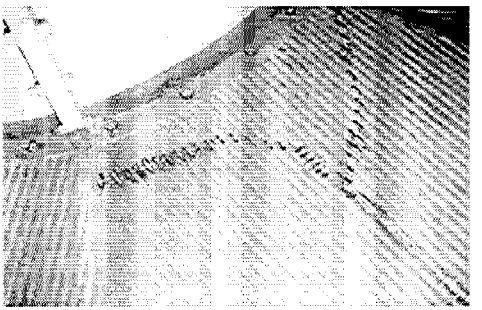

Figure 4: Repair made by metal stitching, floor plate Lighthouse Den Helder.

This is a cold technique that can be used to repair cracks. Locks are inserted at right angles to the crack and the crack itself is closed with studs. For the locks holes are drilled at regular intervals. The material between the holes is cut out so that they are joined and the locks, which are made of a special alloy, are inserted into these spaces. Threaded holes are then drilled along the crack and into these studs are screwed thus closing the crack. This is done in such a way that the studs overlap each other (Figure 3). After this the joint is ground smooth. With this method the original strength can usually be restored. The locks take up the tensile force perpendicular to the to the crack, while the studs ensure that the crack is closed and the transfer of the shear stress.

In places where there is a concentration of stresses, cracks come together or more material has been lost, master locks can be used. These insertion pieces are made to measure and joined to the parent material in the way described above (Figure 3).

2.3 Adhesives

The 'gluing' of metals was developed in the aircraft and space industries and has recently been used in the coachwork industry. Under workshop conditions a strong and durable connection can be made. An adhesive connection provides a uniform transfer of forces, but considerable skill is required in the application of the adhesive. The use of adhesives is relatively new in civil engineering but could provide an attractive method for repairing broken cast iron elements.

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3. Repairs to wrought iron and steel

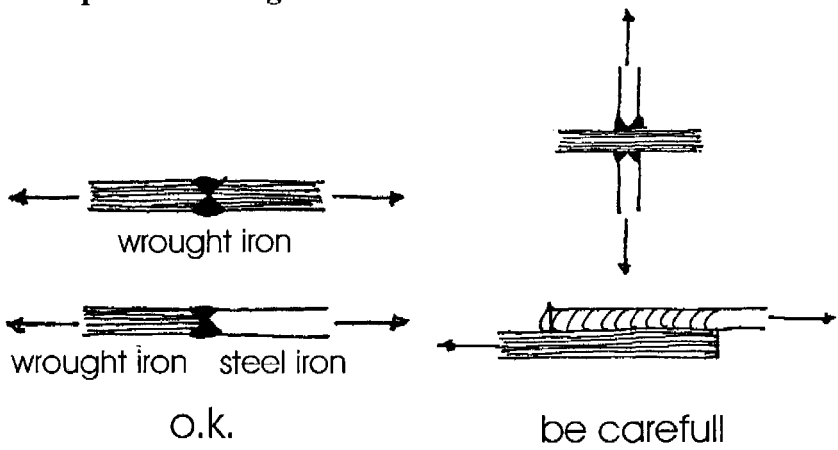

Figure 5: Welding wrought iron. A strong joint can be obtained in the direction of rolling, but care must be taken with joints at right angles to the rolling direction or joints under shear load.

When repair or strengthening is necessary, welding, bolted joints and, in principle, adhesive methods can be considered. Wrought iron can be welded, but during the rolling process contaminants have resulted in the development of a laminar structure. In the direction of rolling a strong connection can be made, however at right angles to the rolling direction and also when the material is loaded by shear forces caution is advised (Figure 5). When part of a rolled profile is seriously corroded the damaged part can be sawn or ground out and new material can be welded in (Figure 6). A profile can be strengthened by welding on plates or strips (Figure 7). Siemens-Martin steel is usually suitable for welding but with Thomas steel there is a risk of brittle fracture.

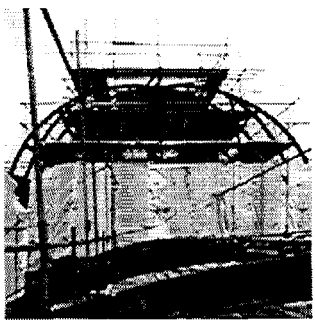

Figure 6: Welding wrought iron. Corroded parts of the upper and lower edges of a profile are ground off and new material is welded on, Palm House, Kew.

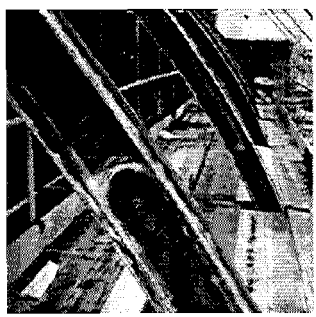

Figure 7: Welding wrought iron. Strengthening of the upper and lower edges of a profile by welding on strips. The wrought iron is loaded for shear stress at the position of the weld, Palm House, Kew.

When wrought iron or other old types of steel are being welded it is necessary to consider the need to investigate whether the material is suitable for welding. For the analysis the laboratory can usually manage with a few metal shavings. Advice can then be given about the filler rod and the welding process.

In addition to the welding on of strips or other profiles strengthening can be obtained by bolting on extra profiles. As has already been mentioned, in civil engineering the use of adhesives is still in its infancy. However a glued joint can provide a good connection with a uniform transfer of forces.

4. The availability of old construction and connecting materials

If the original material has been seriously damaged by corrosion or when parts have been lost or when it requires much strengthening it is necessary to replace profiles or structural elements. Materials such as cast iron, wrought iron and steel and the elements made from these materials must be investigated. After this riveted joints and bolted joints are considered.

4.1 Cast iron

Elements made of grey cast iron, such were formerly used, can be easily obtained. Often they can be ordered from catalogues containing cast iron balustrades, lamp posts, window frames and similar elements. Columns, beams and other structural elements can be re-cast. Foundries are usually equipped to produce items in series. Products may range from very large series to single items and sometimes foundries place restriction on the size of the items they can cast. When elements have to be replaced it is often possible to use the original elements to make the new moulds. If greater tensile strength and reduced brittleness are desired modern nodular cast iron can be used. For cast iron window frames nodular iron replicas are made and this material is certainly to be recommended for beams. For small series of windows or when the budget is limited window modern steel frames may replace frames.

4.2 Wrought iron and old types of steel

Wrought iron, which can only be manufactured by puddle process, is now almost unobtainable. At the Blist Hill site of the Ironbridge Gorge Museum, Shropshire, England, a limited amount of wrought iron is produced as one of the activities of this 'living museum'. In addition it is possible to melt old wrought iron and to roll it again. Old profiles can only be rolled to a limited extent. In Whaley Bridge, Cheshire, England there is a rolling mill that can make simple profiles such as flat, tee and angle sections and glazing bars. By means of mechanical forging the desired profile can be formed from a standard glazing bar.

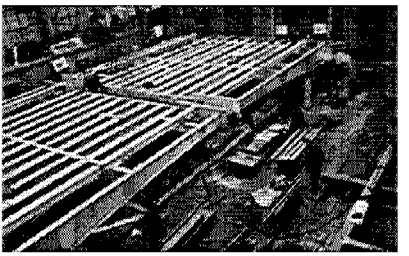

Figure 8: The bascule of the Spanjaardsbrug Rotterdam, was so severely corroded that it was necessary to make a replica. The modern steel profiles closely resemble the original profiles. The original rivets have been copied. Calculations indicate that the bridge was sufficiently strong.

Figure 9: Riveted beams are replaced by welded ones. The appearance of the detailing is considerably changed by this, Platform roof HS Station Den Haag

However when elements have to be replaced modern steel profiles are usually used, a profile that is as close as possible to the original profile was chosen. Whenever high demands are placed on corrosion resistance, profiles can be galvanised or stainless steel can be used. Bessemer, Thomas and Siemens-Martin steel are no longer produced. The last rolling mill in eastern Europe that still produced these old types of steel closed in 1990.

4.3 Jointing methods

The technique of riveting is still used. In the Netherlands and abroad there are still a number of companies that can make good riveted joints. As in the case of welding, further investigation the riveting of Thomas steel is necessary, with a view to artificial ageing. For joints that are out of sight in particular, welding is often used. Structural connections that are visible are also often welded and for the visual effect rivet heads are often welded onto the structure. Sometimes people even go so far as to stick on plastic imitations.

Welded joints are cheaper, but the appearance of the structure is considerably changed. However this gives an honest indication that the structure has been repaired. Modern nuts and bolts are available in many types and sizes but the square nuts and bolts that were used in early iron structures are only available to a very limited extent.

5. Conclusion

Firstly, from the point of view of the restoration philosophy it is necessary to consider how the structure should be treated. To a certain extent the financial means will also determine whether restoration will be undertaken, and if so what

methods are to be used. If modern materials and methods are to be used this can be done in such a way that it can only be detected by the experienced eye. Alternatively modern elements may be used in a way that clearly shows restoration has taken place. It can be assumed that repair is preferable to restoration. Moreover it is much cheaper to repair cast iron elements than to replace them. Cast iron or wrought iron and old types of steel can usually be repaired. For cast iron, metal stitching is the first option that comes to mind while for wrought iron, welding is the obvious solution. The use of adhesives sometimes gives a good joint. Further research into this technique is desirable. Broken cast iron elements can always be replace by new ones. If so desired, modern nodular cast iron can replace grey cast iron. Wrought iron profiles are only available to a limited extent and old types of steel are no longer produced. Often it is necessary to use modern steel profiles. The riveting technique has certainly not yet died out.

References

Material from the archives of the History of Structural Design Group, Faculty of Architecture, Delft University of Technology.