Retrofitting of Concrete Building using Steel

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Abstract

The retrofitting of concrete structures becomes necessary when some constructed structures encounter loss of strength and fail to serve the required life expectancy or to enhance the performance of some structures, which have crossed their expected life time. The success of retrofitting depends on the detection of the actual problem the structure is encountering and on the prescribed measures to prevent its further deterioration. The process involves repair, maintenance, renovation and even part reconstruction.

Actually any structure needs periodic maintenance and repair to keep it functioning. The decision of retrofitting arises only in case of exigency. In RCC structures cracks are developed as symptoms of its failure to resist the applied force or its component. The cause of crack may be unique or diverse in nature. The nature and location of the applied loads, its period of occurrence, static or dynamic in behaviour, detailing of reinforcement, uniformity of concrete as material, quality of rebars, failure of bonding between concrete and rebars, corrosion, carbonation and effect of SO_2, saline or aggressive environmental effects etc. are some common causes of failure in concrete structures.

The cause of development of cracks in concrete structures may be classified as either Global or Local depending on the type of failure. The failure in structural system due to either faulty design consideration or deterioration of its one or more components leads to the development of cracks in structural elements and its nature of failure indicates its cause i.e. by shear force, by flexure, by torsion, by biaxial bending, by compression, by tension or a combination of these.

The Local failures do not lead to the failure of the structural system and once retrofitted or replaced the whole structure starts functioning properly undergoing redistribution of reactive forces among the structural components. The Global failures may or may not lead to the collapse of the structure depending on the degree of redundancies in the structural system and the strength of the individual structural components while undergoing redistribution of reactive forces due to reduction of strength or failure of one or more structural components.

Steel elements in the form of Plates, Channels, Angles, I-Sections along with Anchor bolts / Through bolts could be used with proficiency for Retrofitting a damaged RCC building. The paper has elaborated in detail different aspects of cracks developed in concrete structures with remedial retrofitting measures along with sketches and calculation methods. Some generic examples of retrofitting methodologies applicable to Global and / or Local causes of cracks in concrete have been cited in this paper. Along with the conventional measures of retrofitting some special measures / details using steel have also been discussed on case to case basis.

The use of steel sections with anchor / through bolts or adhesives can enhance the strength as well as the life expectancy of the concrete buildings especially in the case of heritage buildings. Using steel profiled sheeting a damaged concrete roof can be totally replaced or retrofitted without making any disturbance to the activity underneath. Steel sections and sheets being lighter their use does not add extra dead load on the existing structure but offers strength to the structural element as well as system.

Key Words

Anchor bolts; Angles; Channels; I-Sections; life expectancy; maintenance; Plates; repair; renovation; redundancy; Through bolts

Detection and Prevention

Any structure needs periodic repairs and regular maintenance to continue its performance of withstanding the existing loads. But due to monotonously changing static as well as dynamic behaviour of the applied loads on it the elements of the structure undergo weirs and tiers and ultimately losing its material properties it develops cracks in the different patterns. In case of RCC structures the cause of the failure could be well detected by studying the nature of crack and its penetration inside the member, which helps prescribing suitable preventive measures so that the life expectancy of the structure does not get impaired.

This process of detection and prevention continues as long as the structure completes its performing age or requires replacement as a whole. As per the reliability studies the conventional design methodology ensures a life expectancy of a RCC building structure as about 70 years. But studies indicate that half way of the expected life the RCC structures develop deteriorating signals asking for its proper retrofitting / renovation. INSDAG had carried out one such study on the bridges of Indian railways, which establishes this fact by lots of examples all over India.

Hence, it is necessary to understand the effective preventive measures against the development of cracks in RCC elements.

Global symptoms and Local symptoms

The structural behaviour and its failure mechanisms could be classified broadly as Global and Local based on the symptoms manifested in its failing members. If the redundancy of the structural system as a Global one is high, the non-performance of a few members does not lead to the absolute failure of the structure till it reaches the state of mechanism through reduction of the redundancy. But the failure of main members may impair the Global system. It is, therefore, easier to carry out retrofitting measures on the structural elements if it is confined to the Local one and does not affect the Global system of the structure.

During and after retrofitting care needs to be taken towards the release of residual stresses due to the existing system and the redistribution of the stresses due to the new system. The best method to avoid sudden release of stresses is to apply stilts near the point where retrofitting measures are going to be applied and give some time to get the residual stresses released slowly. Even after the structure gets retrofitted it is desirable to keep the stilts in place for some time and remove them sequentially so that the new stress pattern in the structural element can be redistributed evenly without effecting any undue stress concentration at any point of it causing cracks.

When the symptoms of failure leads the structure to mechanism i.e. the state of failure it requires additional props / trusses to hold the system during the retrofitting activities. Even sometimes it is required to renovate a part of the structure as a measure of retrofitting because that improves the health of the structure and increases its life expectancy.

Steel Elements used in Retrofitting

Steel elements in the form of Plates, Channels, Angles, I-Sections along with Anchor bolts / Through bolts could be used for Retrofitting a damaged RCC building. The detailing of the joints of Steel members with the cracked RCC members requires study of the nature of crack and its depth and extent in it. Since it is very easy to give the steel members different shapes, it could be detailed in the most favourable way to fit into the system according to its necessity and spaces available. Some specific failures and its retrofitting measures are explained below.

A RCC beam is prone to fail by either flexure and / or by shear force. The stressed zone for shear in the beam is loacated near the supports and cracks develop in the concrete at an angle of 45^0 starting from the point of support. But the stressed area for the flexure is near the span and its failure crack develops vertically. Some sketches suggesting retrofitting details for shear as well as flexural failure are given below.

In some structures the RCC beam may undergo torsional failure, which shows cracks over the peripheral surface of the member. In some specific cases it may also undergo failure due to biaxial bending, which impairs the concrete section through diagonal cracks started at corners of the section and propagate inward at an inclined angle. Some details are furnished below as suggested measure of retrofitting to prevent such failure.

The RCC column may fail as a compression member through buckling developing horizontal cracks at about mid height or it may fail as beam-column with similar nature of cracks. So, it requires close observations to detect the cause of failure in concrete and prescribe its remedial measures. In case of failure of column under compression the concrete will tend to spall off near the point of crack. But in case of beam-column failure such spalling is absent. This is due the dominance of compression force and the bending moment. Stocky RCC columns may fail due to yielding impairing the concrete of the member through crushing and spalling. But such cases are not very common in practice. Suggestive measures of retrofitting in these cases are given below[1].

But the most complicated situation arises when the failure in RCC is effected by the combination of these causes. In such case the detailing of retrofitting requires due consideration of all such aspects. The detailing may be made simpler to make the retrofitted joint take up the different types of loads separately. But depending on the specific requirements the measures of retrofitting could be applied as per the Engineer’s discretion.

In case of excessive differential settlement in the structural system cracks may appear locally at the beam-column junctions, which may lead the structure to mechanism slowly as the crack increases. The philosophy of the RCC design followed worldwide considers failure of the structure through tension modes, which take time to develop and failure of its members, does not occur suddenly as happens in the case of compression mode through crushing. At the joints the reactive forces act in combinations and failure of a joint means reduction of redundancies depending on the number of connecting members, which is not at all desirable. Hence, all the aspects of load combinations need to be carefully considered while prescribing a near full proof retrofitted beam-column connection. Some such details are suggested below.

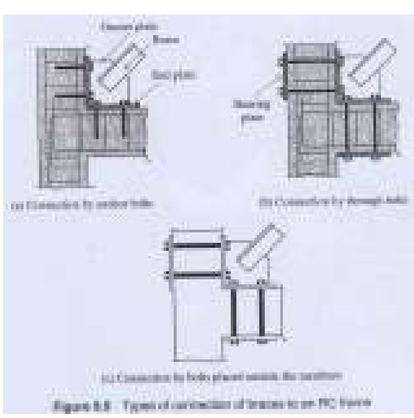
Design methods of Retrofitting Steel members

The design methodologies of retrofitting of RCC structures using Steel elements are described with examples case by case basis. While designing a retrofitting structural element the full strength of the parent members, which are to be repaired, needs to be ascertained and the retrofitting details need to be carried out in such a way that it can withstand the full strength because it is very difficult and cumbersome to assess accurately the loss of capacity of the concrete members, which have undergone deterioration over ages.

Beam-Column Junction [1,2]

Three types of details of the retrofitting system have been shown in the following figures. The horizontal and vertical components of the full strength of the bracing member shall be withstood by the Steel bolts fixed with the column and beam respectively either as inserted or through type.

Type 1 shows anchor bolts inserted within the concrete and Type II shows anchor bolts as drilled through the concrete whereas Type III shows anchor bolts as through type but outside the concrete members fitted with back end plates.



Steel Jacketing of RCC colums (1,3,4)

Existing concrete columns may fail under buckling due to loss of compression capacity by continuous deterioration of longitudinal rebars and subsequent spalling of concrete covers and they may be subjected to excessive shear force during their performing life for which the columns had not been designed and the columns expand laterally. To increase the strength of the columns in such cases the existing concrete is confined within a steel jacket filling the gap with non-shrink grout and thereby its shear capacity is increased and the buckling mode of failure within the height of the columns is also arrested. The different systems of steel jacketing have been shown in the following figures.

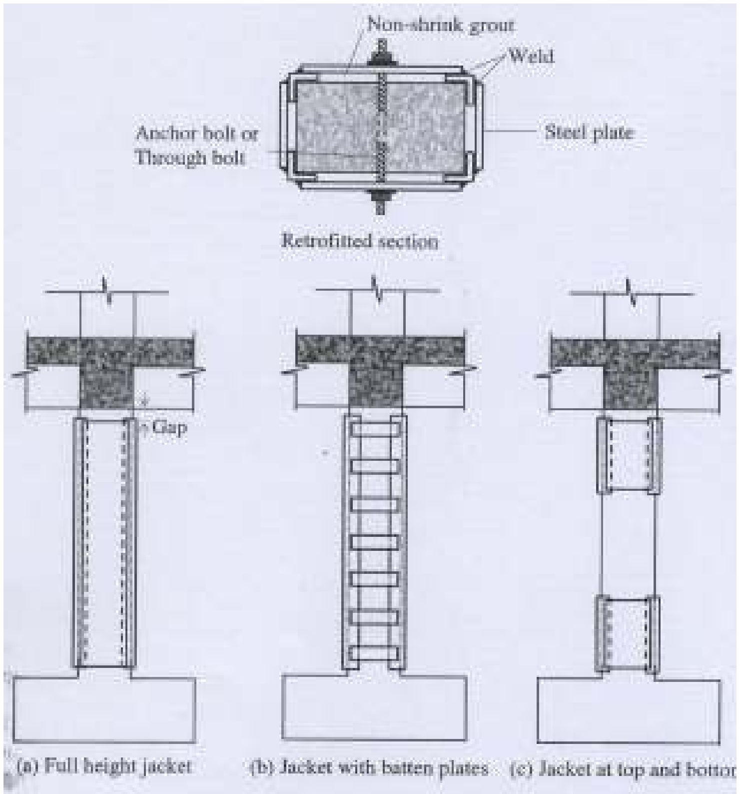


Figure 9.11 Techniques for steel jacketing of columns

As per Aboutaha et al., 1999, the shear strength of the jacket (V_j) can be calculated by considering the jacket to act as a series of independent square ties of thickness and spacing t_{sj}, where t_{sj} is the thickness of the plates. For rectangular columns,

$V_j = A_{sj} \times (f_{sj} \times d_{sj}) / s_{sj}$

Where,

A_{sj} = Total area of assumed square tie = $2 \times t_{sj}^2$

f_{sj} = allowable stress of jacket = 0.5 x yield steel of steel of jacket

d_{sj} = depth of the jacket

s_{sj} = spacing between the square ties = t_{sj}

If the column is not subjected to excessive shear force and the loss of its compressive strength is manifested with continuous propagation of predominantly horizontal cracks, the steel jacket may be extended from one connection to the other and the increased capacity of the jacketed column may be calculated by using the following methods. The ultimate compressive strength Ncu and the buckling strength Nccr of the jacketed column are given by:

$N^c_u = A_c \times r_u \times F_c$

$N^{c}_{cr} = A_c \times \sigma^{c}_{cr}$

Where,

A_c = Cross-sectional area of a concrete column

F_c = design standard strength of existing concrete

σ^{c}_{cr} = Critical stress of concrete column

r_u = 0.85 = reduction factor for concrete

The critical stress, $\sigma^{c}_{cr} = [2 / \{1 + \text{sqrt}(\bar{\lambda}_c^{4} + 1)\}] \times r_u \times F_c$ for $\bar{\lambda}_c \leq 1.0$

$\sigma^{c}_{cr} = 0.83 \times \exp\{C_c \times (1 - \bar{\lambda}_c)\} \times r_u \times F_c$

In which

$\bar{\lambda}_c = (\lambda_c / \pi) \times \text{sqrt}(\varepsilon^{c}_{u})$

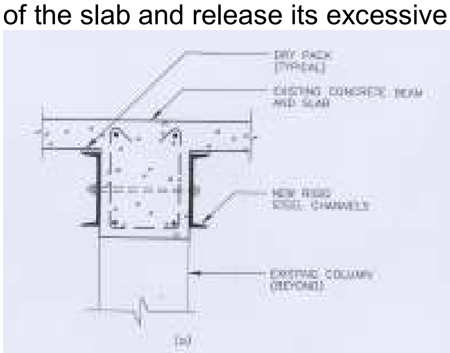
$\varepsilon^{c}_{u} = 0.93 \times (r_u \times F_c)^{0.25} \times 10^{-3}$

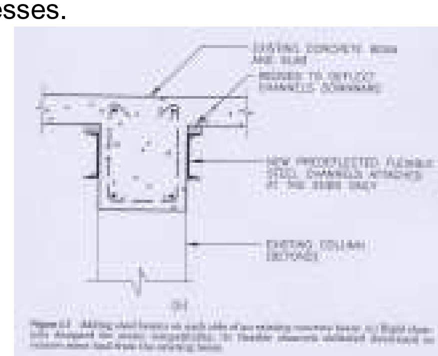
$C_c = 0.568 + 0.00612 \times F_c$

λ_c = Slenderness ratio of the concrete column

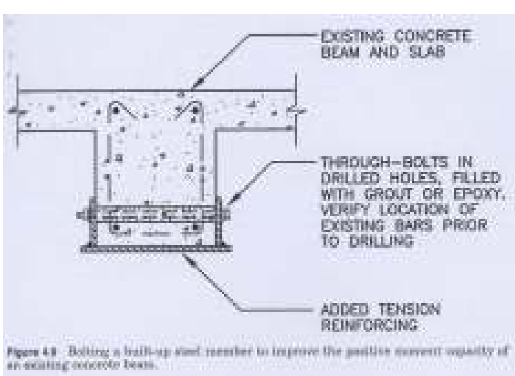
Strengthening of RCC beams [1,2]

Additional steel beams connected through the concrete beam by steel bolts share the load and relieve the concrete of its stresses. The load is shared proportional to the relative rigidities (EI) of the existing concrete beam and the added steel beam. There should not be any void in between the steel beam flange and the concrete slab. It should be dry packed with wooden wedges. Otherwise horizontal bracing system needs to be introduced in between two steel beams to reduce the lateral torsional buckling of the additional members. Sometimes flexible channel sections could be wedged from underside the slab while giving an upward deflection of the slab and release its excessive stresses.





While retrofitting a RCC beam failing in flexural tension the additional requirement of tensile reinforcement is compensated as shown below.



Case Studies

Renovation of Roof of Church in West Bengal

The roof of a church in West Bengal required to be renovated without disturbing the masses going underneath. Steel profiled sheets had been placed below the damaged roof with the help of Steel beam grids as supporting structure. The existing roof was removed with jack hammers and the new one was cast with RCC over the Steel sheets, which acted as sacrificing shuttering material. In this case the thickness of the new roof could be optimized by use of Embossed profiled Steel sheets instead of Plain profiled Steel sheets because it reduces the requirement of rebars and thickness of the concrete section.

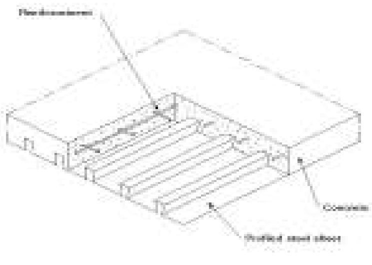
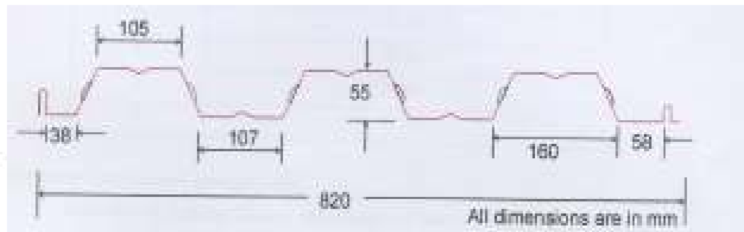
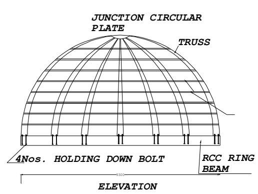


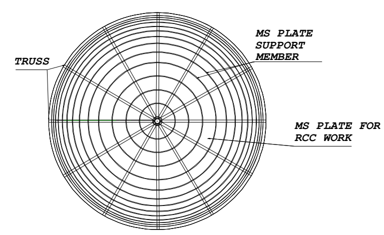
Figure 1 Composite slab with profiled steel sheet



Dome of a Heritage Building, West Bengal

The Dome structure of a heritage building in West Bengal needed to be reconstructed because it was weired out over ages. Steel frames bent in the shape of the dome along with thin Steel sheets have been fabricated and placed below the existing concrete structure. The deteriorated old concrete was removed with jack hammer without disturbing the official activities going underneath and new concrete was cast with some shear studs made of Steel flats monolithically inserted within it. The steel support had been kept in place as permanent shuttering, which also adds aesthetics to the dome structure.





Bracings in Building in Kolkata

In Kolkata the columns in one heritage building have been relieved of bending stresses by addition of cross bracing systems using Steel angles, plates, bolts etc. By use of bracings the moment resisting type of the frame and its members has been converted to braced frame type and the members were subjected to axial loads only. In this way the columns were relieved from the flexural stresses induced in them due to the existing system.

Some original special Recommendations

Sometimes in specific cases unconventional structures are required to be designed and constructed. Hence, the nature of cracks developed in the concrete is so diverse that it becomes very difficult to detect the cause of the failure and hence, prescription for its remedial measures becomes very difficult. As a case study the cracks observed in a Stock Pile structure could be discussed. The structure was overloaded to double its capacity for over about seven (7) months. After a few weeks cracks of different patterns started to develop in the concrete hopper walls, its supporting beams and the expansion joints got separated slowly. The nature of cracks were varied and it was a very difficult scenario to detect the causes of such failures so that the structure could be retrofitted and be back to its operation. The analysis of the structure in computer was done and depending on the location of cracks as the weaker points the excessive stressed zones were relieved through additional supporting members. While doing so additional parts were connected to the existing structure with such rigidity that maximum forces were drawn by these additional members.

The cracked members were retrofitted with steel elements as discussed earlier and the connection of old and new structural systems were done with steel plates, through bolts etc. to take care of the reactive forces like shear, bending moment etc.

Observations and Conclusion

The life expectancy of the RCC structures is facing the test of time. Hence, the actual performance of the concrete structures as manifested after withstanding different types of stresses and their distribution and redistribution caused over its period of performance necessitates its retrofitting through proper measures to make it functional for the rest of its life. Steel has a very high strength to weight ratio and it is available in different shapes or it could be rolled or folded to the desired shapes. The quality of steel is maintained through QAP followed in the workshop of the producers. Hence, the retrofitting of the RCC building could be executed using different steel elements ensuring the safety and longevity of the deteriorating structure.

If the Global symptoms of failure are vivid, the total structural system needs to be reanalyzed with the weak links at cracks and trials need to be taken for the redistribution of reactive forces through inclusion of additional structural members, if possible, to relieve the overstressed members. It is also easy to keep maintenance and repairs of the retrofitted part with steel members and in exigency the steel parts could be replaced immediately and at ease.

Heritage structures need special sensitivity in retrofitting so as not to disfigure their appearance and many such buildings have been successfully reconstructed in different countries. We often come across disasters of old buildings, some of which are declared heritage buildings, due to ageing and loss of strength of the materials of construction. The life expectancy of such buildings could be enhanced considerably by using steel in special details by which the damage of the structural elements like columns, beams and slabs could be repaired or retarded.

The discussion has elaborated the beneficial aspects of the retrofitting using steel elements and it is expected that its use will be popular in India gradually.

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