INVESTIGATION OF THE STEEL JACKET RETROFIT METHOD FOR SOFT STOREY STRUCTURES

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ABSTRACT

Often columns that have undergone failures due to an earthquake or due to any other reason need to be restored and/or retrofitted. For columns, one retrofit method is the steel jacket method which deals with the restoration of both the longitudinal and the transverse reinforcement. However, when dealing with the restoration of the transverse reinforcement only, another method is used, that of the metallic collar. The aim of this paper is to examine the ways in which a steel jacket can be used when retrofitting columns, shear walls, and support columns from masonry. Furthermore, the attainment of constriction of the steel jacket and the existing column by the use of metallic tiles as wedges is discussed. Finally, it is concluded in this paper that the steel jacket method is a very old and good method for retrofitting existing columns. It is a fast and easy method that can be applied in a construction site and last but not least it is an affordable method.

KEYWORDS

Retrofit method, soft storey structures, columns, steel jacket, steel angle sections, steel plates, resinous stucco.

INTRODUCTION

In general, retrofitting columns with the steel jacket method is a very old and good method. Indicatively, it is mentioned that in the Church of Saint Barbara in Athens, Greece, which was approximately constructed in 1903 the use of the steel jacket method in masonry support columns was ascertained.
As shown in “Figure 1” above, elements of steel jacketing were forged in fire since welding did not exist back then. Thus, corner pieces were shaped as shown in “Figure 1” which interlocked loosely onto strong vertical steel plates that were placed in the midway on each side of the column. The columns were then constricted using wedges.

**BENEFITS WHEN USING THE STEEL JACKET METHOD**

The steel jacket method is a very good method for retrofitting an existing construction with many benefits. It is a fast, easy, and affordable method. Furthermore, in some cases, it is the best method that can be applied on site since the cross sectional area of a column increases very little compared to other methods. Thus, the method is ideal when dealing with e.g. partition walls, shops etc.

When applying the steel jacket method, the aim is to achieve the complete interface of the steel jacket with the existing concrete of the column. This means that adhesion tensions should be developed between the steel jacket and the existing column. However, in practice, this complete interface is very hard to achieve when trying to apply any of the methods that various guidelines specify. The reasons that cause these difficulties are mentioned below:

First of all, concrete support columns almost never have flat surfaces in height, as they are required to have. This is because of the bad construction of the formwork as well as the pure concrete placement. Thus, both result in the bad appearance of the column with a corrugated form or with local broadenings or voids or even a deviation from the vertical. On the contrary, the steel jacket method guarantees flat, rectilinear surfaces. Also, the coupling between the steel jacket and the existing column highlights the concrete’s imperfections.

Furthermore, the so called “stretching” of the bolts, is also a subjective and a precarious action one may use in order to achieve the complete interface described by most guidelines. Two things may happen during this constrictive work. Either the volutes (threads) of the bolts will get destroyed, or the column’s concrete edge will break (weak position of the concrete in the stretching area).

Last but not least, heating steel plates, welding them to the steel jacket and finally having them stretched thereinafter due to thawing, is a method that may be applied only theoretically on a construction site. Placing a steel plate on the side of the column which is adjacent to a partition wall is very difficult if not rather impossible.

Thus, for all the reasons mentioned above, the method of steel jacket is not yet in some countries a widely applicable solution.

**DESCRIPTION OF THE CONSTRUCTION OF A STEEL JACKET**

For the construction of a steel jacket the careful and meticulous cleaning with sand blasting or any other suitable method is required on the surface of the concrete, where the steel jacket will be placed. This is done in order to ensure the positive interface of the steel jacket with the existing column and the successful use of resinous stucco. For increasing the stucco – concrete adhesion clear dust free concrete surfaces are required.

For the construction of the steel jacket, steel angle sections with a minimum section of L50×50×5 are placed on the edges of the column. These angle sections are constricted with special wrenches called “pipe vices”. This constriction takes place in order to minimise the voids between the existing column and the steel jacket and not in order to achieve interface, as one may have thought. Next, steel plates are placed having a distance between them of maximum half a meter which are welded to the angle sections as shown in “Figure 2” below. Once welding is completed the construction is tested acoustically. By percussion on the steel jacket the sound of a vacuum is heard. Thus, small wedges, varying in thickness, are placed in the voids between the steel jacket and the column. The wedges are placed in pairs or more and they are always placed in
such a manner so that their overall thickness is greater than the thickness of the gap which is created between the steel jacket and the existing concrete column. During the impact of the wedges, each part of the wedge enters in the gap between the concrete and the steel jacket, see “Figure 3”. Thus, by utilising the various friction coefficients steel to steel and steel to concrete, wedges larger in thickness are placed in thinner gaps. This additional thickness of the wedges accomplishes the constriction of the steel jacket by reducing the voids between the existing column and the new construction to a minimum.

Next, an acoustic test is carried out once again. Once the wedging is done the percussion sound of the construction is heavy. This indicates the continuity in mass thus, the complete interface of the two materials. The wedges are then welded and the steel jacket is coated with an anti-corrosion inhibitor. The steel jacket is then coated with resinous stucco in order to protect it from oxidation, after having previously filled all the voids between the steel jacket and the concrete with resinous stucco. Special caution must be taken in the transition area from the steel plate to the surface of the concrete. This joint must be thin and flat in order to be able to take the tensions that will be created due to friction, as shown in “Figure 4” below. Finally, the steel jacket is smeared with silica sand in order to create irregular surfaces thus, a better adhesion with a future plaster coating, see “Figure 5”.
It should be noted that in the case of a shear wall due to the long length of the steel plate and thus, its big deformations, one must anchor the steel plate wherever this is considered necessary. This is achieved many times with the use of pins. The pins permeate the entire thickness of the shear wall, wherever this is possible. Wherever this is not possible, anchoring takes place on the one side only. A hole is broached in the concrete and the pin is placed and welded on the plate. Finally, it is coated with resinous stucco. In theory, the support column is ready to take loads, provided that constriction is achieved and there is complete interface between the steel and the concrete construction. From the aforementioned a steel jacket is constricted by wedges and the interface between the two materials is achieved firstly by the additional thickness of the wedges and secondly by the use of the resinous stucco. The resinous stucco increases the friction coefficient between the steel jacket and the concrete due to its great adhesion strength with the concrete. Note, adhesion tests of resinous stucco on concrete specify up to 61.20 Kp/cm².

**CALCULATION OF THE STEEL JACKET**

From the reinforced concrete theory one knows that the two materials concrete and steel interface because they have approximately the same thermal coefficient of temperature. Thus, it is impossible to create secondary tensions later. The percentage of the steel surface (existing and new) in a column is not permitted to exceed a
certain percentage in relation to the surface of the concrete. According to previous DIN standards: \( F_e = 0.08 \times F_b \) and in proportion to the category of the concrete. The reason why the standards foresee this provision is due to the redistribution of forces that is conducted between the reinforcement and the concrete due to creep. Note, there is always a risk of overloading the reinforcement due to redistribution and there is a risk of destruction due to buckling. When designing the support columns, the addition rule applies. This means that the durability of the concrete construction and the durability of the steel jacket construction are added and the resulting sum is that of the load bearing capacity.

From the above it is concluded that in order for the steel jacket to interface with the existing concrete construction adhesion forces should be developed between them. These adhesion forces should be at least the force that the steel jacket can take. In other words, the following equation should apply:

\[
R = \Sigma F_e \cdot \sigma_{\text{allowable}}
\]  

where:
- \( R \) = the friction force that is transferred from the steel jacket to the existing concrete construction
- \( F_e \) = the surface of the steel
- \( \sigma_{s(allowable)} \) = yield stress

Furthermore, the following physics formula is known:

\[
R_{Rd} = \mu (N_{vo} - \Delta N_{v,k+s}) \cdot \frac{1}{Y_v}
\]  

where:
- \( N_{vo} \) = the axial thrust that is achieved by the wedges
- \( \Delta N_{v,k+s} \) = the losses of force due to creep and shrinkage of the column’s concrete and for safety reasons it is estimated to be 40% of \( N_{vo} \)
- \( \mu \) = the friction coefficient between the steel and the concrete is estimated approximately 0.50 for unrefined steel surfaces without oxidation, painting, and grease residues.

Thus, the maximum \( R \) friction force is calculated according to Eq. (1) and the required axial thrust \( N \) for achieving the necessary friction force is calculated using Eq. (2). Thus, the problem exists in calculating force \( N \) from the wedges’ thickness. Therefore, if one accepts that the two steel angle sections and the steel plate form a static load bearing system as shown in "Figure 6" below then from the strength of the materials the following equation is known:

![Figure 6: Fixed end beam](image)

\[
f_{\max} = N \cdot c^2 (3c_1 - c) / 24EI
\]

Eq. 3 gives the maximum deformation due to load \( N \). From Eqs 1 and 2, one can calculate force \( (N) \). Thus, the additional thickness of the wedges can be calculated in order to achieve the \( N \) force.

**EXAMPLE OF THE STEEL JACKET RETROFIT METHOD**

Assume an existing support column with dimensions 35×35, and reinforcement 4Φ18, with a storey height 3.0 m and with steel angle sections L50×50×5. Thus, the reinforcement percentage is:

\[
F = 4 \times 4.80 = 19.20 \text{cm}^2
\]  

Reinforcement percentage check:
\[
10 + 19.20 / 35 \times 35 = 0.02 < 0.08 \text{ thus, acceptable} \tag{5}
\]

Steel jacket force:
\[
R_{\text{max}} = 19.2 \times 14000 = 268.8 \text{kN} \tag{6}
\]

With a friction coefficient \( \mu = 0.50 \) the axial thrust is:
\[
N = 268.8 / 0.5 = 537.6 \text{kN} \tag{7}
\]

With a 40% augmentation of the axial thrust due to creep:
\[
N = 1.4 \times 537.6 = 756.4 \text{kN} \tag{8}
\]

If two wedges are placed with a 5 square centimetres surface each per horizontal plate and 10 pieces are placed 300/10 = 30 centimetres distance from plate to plate and per support column side, it is concluded that:
\[
10 \times 4 \times 2 \times 5 = 400 \text{cm}^2 \tag{9}
\]

Permitted pressure tension of concrete:
\[
756.4 / 400 = 1.89 \text{kN/cm}^2 < \text{Permitted pressure tension of concrete} \tag{10}
\]

The required axial thrust \( N \) per plate is:
\[
N = 756.4 / 4 \times 10 = 18.9 \text{kN} \tag{11}
\]

The additional thickness of the wedges that causes friction for axial thrust per plate 18.9 kN and total thrust \( \Sigma N = 756.4 \) kN is:
\[
f_{\text{max}} = 18900 \times 5^{\frac{3 \times 20 - 5}{24 \times 2 \times 21000000 \times (10 \times 0.5^3 / 12)}} = 0.495 \text{ cm} \tag{12}
\]

In reality due to the coating with resinous stucco in order to protect the steel jacket construction from oxidation, the friction coefficient increases more than double and thus \( \mu = 1 \) instead of 0.50. Furthermore, the adhesion of the resinous stucco with concrete as is aforementioned amounts approximately to 0.612 kN/cm\(^2\) thus, the length of the weld is:
\[
4[(35 - 5) \times 10] = 1000 \text{ cm} \tag{13}
\]

Multiplied by one centimetre which is the width of the weld gives a surface of:
\[
1 \times 1000 = 1000 \text{ cm}^2 \tag{14}
\]

and that in force is:
\[
1000 \times 0.60 = 600 \text{ kN} \tag{15}
\]

This means that an additional 600 kN acts as a resistance force apart from the friction due to the wedges. Thus, the construction is secure and no further resin needs to be placed in the voids between the wedges and the concrete for a safer construction, as some colleagues may believe.

**THE CONSTRUCTION OF COLLARS**

The construction of collars is affronted by using the same technology as in cases where there is a problem in a column’s transverse reinforcement. Thus, if the fasteners of a column are inadequate in number or have been oxidised and do not constrict the vertical reinforcement of the column well enough, then the construction of collars as means of additional transverse reinforcement is required in order to improve the structure. The construction of collars is done in the same way as with an entire steel jacket, only of course the vertical steel plates are excluded.
SHEAR WALLS

The failure of a shear wall is usually not caused due to the reduced strength of the material but due to the particular behaviour that they present in a construction. Thus, as it is mentioned in the paper by Karatzas (2012) with title “Behaviour of compression members with EI→∞ under axial loads” when the rigidity of the shear wall is great in relation to the rigidity of the beams resting on them, and when large horizontal seismic forces are created in the area, then antimetric deformations on the beams are created thus shear walls fail. See “Figure 8” below.

Figure 8: An elastically restraint beam undergoing horizontal loading

Thus, the reinforcement of the shear walls also needs to take into account the possible behaviour of the beams resting on them. Therefore, as a conclusion it is necessary to apply beam jacketing when dealing with shear walls.

However, beam jacketing is also necessary for an extra reason when dealing with shear walls and soft storeys. From the paper presented in Tokyo on May 2013 by Karatzas V., Karatzas E., and Karydis G. with title “Behaviour of compression members with EI under axial loads” the following equation is true:

\[ \psi_2 = I + \frac{c_1}{c_2} \frac{h_1}{c_2} \sum P_i \]

(16)

where \( \psi_1, \psi_2 \) are the angles of obliquity of the first and second members of a multi-storey construction \( c_1, c_2 \) are the rotational spring constants of the first and second members, \( h_1 \) is the height of the first storey, \( \Sigma P_i \) the sum of the overhead storeys. Thus, the following is concluded:

The size of the \( \psi_2/\psi_1 \) ratio depends on the ratio of the spring constants \( c_1 \) and \( c_2 \) and the \( c_2 \) value. For \( c_2\rightarrow\infty \) the above equation gives \( \psi_2/\psi_1 = I \) that is the two members act like one member. Therefore, it is concluded that the greater the \( c_2 \) is in relation to \( c_1 \), the smaller the deviation of the \( \psi_1 \), and \( \psi_2 \) values. Furthermore, the authors
of this paper ascertained that the larger the $\Sigma P_1$, the smaller the $\psi_2/\psi_1$ ratio becomes. Thus, in areas where vertical seismic components $\pm 50\%$ of the existing loads are developed, there is a corresponding alternating fluctuation of the $\psi_2/\psi_1$ ratio and great possibilities for failures of the nodal points of that position. As a conclusion, the reinforcement of the joints with steel jacketing for columns and beams is considered imperative for all the aforementioned reasons.

SUPPORT COLUMNS FROM MASONRY

In formerly existing constructions with masonry columns that need to be reinforced, the steel jacket method can be applied. In those cases, the steel collars that will be used have to be of a particular cross sectional area, i.e. minimum steel angle sections L50x50x5mm and for the steel plates a minimum 6x100mm as shown in “Figure 9” below. With the help of the steel plates and the wedges one can achieve the constriction of the columns however, without the wedges being in contact with the columns’ masonry as shown in “Figure 9”.

CONCLUSION

The steel jacket method is a very old and reliable method that can be used for reinforcing existing support R.C. or masonry columns. It is a fast and easy method that can be applied in a construction site without much hassle. Furthermore, it is an affordable method. The cost of the steel jacket method is more or less the same or in many cases even less compared to the cost of the retrofit method using concrete caissons. Therefore, the steel jacket method should be applied without hesitations. Furthermore, in some cases the steel jacket method is the only method that can be applied on site since it increases by very little a column’s cross sectional area while it causes less hassle compared to other methods such as the gunite concrete method. Thus, it is a great method to use when dealing with i.e. partition walls, shops, residences etc.

REFERENCES

Karatzas E. & Karatzas V., 2012, “Behaviour of compression members with $EI \rightarrow \infty$ under axial loads”