Application of Brace Reinforcement System in an Existing Structure

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SUMMARY

In this paper is described the application of a brace reinforcement system in existing structures in Italy. The structures are made by concrete and were built 30-40 years ago. The problem connected to the high seismic risk increased during the last years and, particularly in Italy, this problem involves many old structures. The proposed operation is the introduction of reinforcing elements to dissipate the energy due to the seismic event. The introduced elements can dissipate energy by plastic axial deformation taking into consideration the buckling effect. This solution can guarantee a perfect biaxial behaviour; which is also constant with different applied velocities. Basing on these characteristics, this application surely gives a and also the modelling phases of the brace element is more related to the matter. The devices are made by a special type of steel which has high ductility performances to have all the required characteristics by the design.

Keywords: old concrete building, retrofitting, brace reinforcement

1. INTRODUCTION

Italy, as for many others European countries, is in a very particular situation concerning the general condition of a lot of existing buildings and structures. A lot of building are related to an old concept from the construction technologies point of view, indeed a lot of them are concerning from 70's or still before until some centuries ago. Many of those mentioned structures, still now, cover an important rule from a strategic and cultural point of view; in fact, above to represent the historical-cultural heritage of Italy (as for others country), in some of them are placed a lot of institutional offices, important for the efficiency of the country as: city hall, hospitals, schools, courts, etc.

One of the most relevant problems connected to the administration of those structures is connected to interface the real structural behaviour related to the new standards or technical improvement. Obviously from this point of view, a strategic importance is connected to the seismic risk. Just the seismic risk represent the main problem for a country as Italy; in fact, from the following picture (Figure 1.1.), is easy to see how this problem is relevant for all the country.

Due to those reasons, and also from the economical point of view, in most of cases is not possible or acceptable to demolish the buildings and so is interesting find some solution (Figure 1.2.) in order to adapt them with the new structural demand; generally speaking is possible to say that there are three main possibility and, case by case, is possible to chose the best solution considering the followings main aspect: structural reinforcement, install isolation devices or install a brace reinforcement system.

The purpose of this paper is to show how the solution with brace reinforcement system will be the more suitable system in order to adapt the behaviour of the structure without modify the general outlook of the structure. It will be also shown the importance to use an efficient brace reinforcement system referring particularly to some technical characteristics of the devices: have a perfect bi-axial behaviour, high ductility of the deformed material and prevent any buckling effect.

Those elements will be described making reference to some projects where this system was applied.



Figure 1.1. Map of the seismic risk in Italy



Figure 1.2. Different effects due to the application of different retrofitting system

2. CHOISE OF BRACE REINFORCEMENT AS RETROFIT TECHNOLOGY WITH REFERENCE TO A PARTICULAR CASE (STRUCTURE IN L'AQUILA)

The project from which will begin the study and the application of the brace system is the retrofit of the main office of an Italian telephone company in L'Aquila (Italy) after the earthquake occurred the 6^{th} April 2009 (Figure 2.1.). After the seismic event it becomes urgent to repair this structure in order to put right as soon as possible the functionality of the structure, that is particularly important because any day passed in temporary structure will cost a lot of money for the own company and the generally efficiency could be compromised.

The choice of brace reinforcement system as retrofitting technology was taken because this approach can fully guarantee all the main requirement of this project; the most important is that the functionality of the structure have to be totally maintained, moreover is not allowed any changes for the architectural distribution of the internal spaces and also any new connection element as expansion joint. All those straight rules are given in order to preserve the functionality and the safety of the internal instrument.



Figure 2.1. Structure in L'Aquila after the earthquake (6th April 2009)

Following the mentioned causes, and also for other reasons as the cost and the general time of the fitting activity, the described solution was chosen; another reason was that with this technology is possible to give to the structure an high property of ductility in order to avoid any damage in any future earthquake.

In accordance to those concepts has to be designed the distribution of the reinforcement in order to optimize the dissipation of energy considering the deformability of the original structure and the distribution of the masses in the. In the following picture (**Figure 2.2.**) is possible to see how are placed the devices and in the following chapters will be described their technical characteristics; the main properties of the devices are the yielding force of each device and the relative deformation.



Figure 2.2. General plant of the structure showing the placement of the brace reinforcement

3. BRACE REINFORCEMENT DEVICES: GENERAL TECHNICAL CHARACTERISTICS AND PLACEMENT

The devices work and can dissipate energy for the axial deformation of a steel element; in particular the behaviour of the devices is to dissipate energy in the axial axis by elasto-plastic deformation of an internal steel element. The design values are belong from a non-linear dynamic analysis where, after an iteration process, are defined two different kinds of devices: one type apply in the longitudinal direction and one apply in the transversal direction. An important detail that has to be checked during the analysis is to control the ultimate deformation of the devices, that is important for the design of the device but, moreover, for control the deformation of the structure. In fact the devices are placed as for the sketch here below (Figure 3.1.) and is possible to see that the axial deformation of the brace is stringently connected with a deformation of the columns of the structure. Finally is possible to say that in the design is necessary to find the perfect behaviour of the reinforcement device in order to optimize the dissipation capability without cause a damage in the primary and rigid structural elements; that is the reason why is important to check exactly the situation of the existing structure before to apply this system: from the structure and from the ductility point of view.



Figure 3.1. General position of the brace reinforcement in the structure

In this particular case, in order to respect the general condition described, was necessary to place the devices with a little internal angle α (Figure 3.1.); in this way with a little horizontal deformation of the structure the axial deformation of the brace element is sizable for guarantee a correct behaviour of the structure: following that the devices, during a earthquake event, are correctly activated and the greatest part of the energy will be taken by them and dissipated. Here below (Figure 3.2.) is shown the precise technical behaviour of the devices used in the two directions:



Figure 3.2. Technical characteristics of the devices in the two main directions

Is interested to check how in the longitudinal direction the total load taken by the reinforcement is higher respect to the transversal one. This is in reason that in the longitudinal direction the structure is more rigid and so is subject to a seismic action bigger then in the other direction; therefore is necessary to dissipate an higher quantity of energy.

An important consideration is that the ultimate and yielding axial force of the devices shall be obtained directly from the dynamic analysis and the rigidity is calculated in order to obtain exactly the described deformation. For guarantee a perfect behaviour all the secondary elements of the devices: the connection elements and the rigid reinforcement elements have to be absolutely strict.

4. PECULIARITY OF THE PROPOSED TYPE OF BRACE REINFORCEMEN SYSTEM

In the previous chapters are described all the general characteristics of this kind of solution, now can be interesting to check which are the peculiarity of the this particular kind of brace reinforcement proposed. All the characteristics described here below are important in order to guarantee that the correspondence between the theoretical and the effective behaviour of the devices.

4.1. Constraint of buckling effect

The devices shall work, as said, with a bi-axial behaviour; due to the high flexibility of the steel of the deformable bar, important for obtain the required characteristics, is necessary introduce an secondary element for prevent any buckling effect during the compressive load. Is also important that this secondary element don't avoid the behaviour when the tensile load is applied. In the proposed solution this secondary reinforce structure is made by a guide made totally by construction steel.



Figure 4.1. Brace reinforcement element: Restrain guide element

As shown (**Figure 4.1.**) the main advantage of this solution is that there is not any mechanical interaction between the steel bar and the restrain guide; for this reason is possible guarantee that the behaviour of the bar is precise and not influenced by the restrain guide.

Another additional quality of this solution is that, due to the light weight of the restrain system the installation and the transportation of the device is easier.

4.2. High ductility of the steel bar

In order to have a device with very high performancy is important to guarantee some important characteristics of ductility. The first is to have a good ratio between the yielding and the ultimate displacement:

$$\frac{d_u}{d_y} \ge 10 \tag{5.1}$$

The behaviour have to be constant for during the cycles of displacement, in particular the maximum load at ultimate displacement has to be in accordance to the following formula:

$$\frac{F_{u1}}{F_{u20}} \le 1,1$$
 (5.2)

Only if those characteristics are guarantee is possible to guarantee a perfect efficiency of the device during a seismic event; without any damage at the devices and, consequently, to the structure

5. LABORATORY TEST: RESULTS

As for any project, for this one is necessary to perform a prototype test for any kind of brace reinforcement (one for the longitudinal and one for the transversal direction). Here below will be shown the main results belong to the laboratory tests. With particular interest were performed dynamic test in order to check all the technical characteristics described in the former chapter, with particular emphasis to the secondary elements introduced for problems connected to the buckling stability.

The tests (Figure 5.1. and Figure 5.2.) are performed with many cycles at different percentage of displacement at the velocity of 50mm/sec; this velocity can guarantee to consider all the dynamic effects during the test.



Figure 5.1. Dynamic test performed at one of the prototype elements



Figure 5.2. Detail of the device during the dynamic test

Device type	First test	Second test	Third test	Fourth test
Longitudinal element	+/- 5 mm	+/- 10 mm	+/- 20 mm	+/- 20 mm
(Fmax = 270kN)	5 cycles	5 cycles	10 cycles	10 cycles
Transversal element	+/- 5 mm	+/- 10 mm	+/- 20 mm	+/- 20 mm
(Fmax = 370kN)	5 cycles	5 cycles	10 cycles	10 cycles

Table 5.1. general data for the dynamic tests at the prototype

In the table are summarized the type of tests performed and here below will be shown the most relevant diagram in order to confirm what was described:

5.1. Longitudinal brace reinforcement (Fmax = 270kN)

From the diagrams (Figure 5.3.) we can firstly see that the behaviour of the device is stable in all the steps of the cycles. Is possible to say that the quality of steel used and the buckling restrain system installed can guarantee a very efficient system. In fact at any test all the cycles are almost perfectly overlapped.



Figure 5.3. Test's diagrams for longitudinal devices

A positive check is related to the ratio between the maximum compressive and tensile load; the ratio is not more then 10% and that is due to the characteristics of the buckling restrain system.

Another positive check is related to the little hardening effect of the material after the many cycles (third test and fourth test). Also this effect do not exceed the 10% and that is due to high ductility characteristics of the material used.

5.2. Transversal brace reinforcement (Fmax = 370kN)

For this device are still valid the considerations valid for the longitudinal brace reinforcement, here below are shown the relevant diagrams (Figure 5.4.)

A positive check is related to the ratio between the maximum compressive and tensile load; the ratio is not more then 10% and that is due to the characteristics of the buckling restrain system.

Another positive check is related to the little hardening effect of the material after the many cycles (third test and fourth test). Also this effect do not exceed the 10% and that is due to high ductility characteristics of the material used.



Figure 5.4. Test's diagrams for transversal devices

6. CONCLUSIONS

The introduction of a brace reinforcement system can be a good solution in order to install an efficient and advanced technology for avoid any risk for the structural behaviour of a structure during and after a seismic event. The installation of this system should take under consideration some peculiar phenomena, if those phenomena are neglected the general behaviour of the structure can be compromised. In this paper are described some solutions suitable to produce devices fully conform with the design and for obtain a very efficient retrofit system.

Also important is, due to the characteristics of this kind of devices, to avoid any risk connected with the buckling stability.

REFERENCES

- N. Lakshmanan (2006): Seismic evaluation and retrofitting of buildings and structures. *Journal of Earthquake Technology, Paper No. 469, Vol. 43, No. 1-2, March-June 2006, pp. 31-48*
- C. Christopoulos, A. Filiatrault (2001): Principles of Passive Supplemental Damping and Seismic Isolation, Iuss Press, Italy