EXAMINATION OF NEW DEVICE OF STEEL ANTI-SEISMIC ELEMENT FOR THE PURPOSE OF STRENGTHENING OF REINFORCED CONCRETE BUILDING STRUCTURES

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ABSTRACT :

During the last years, several researchers propose, the partial or whole replacement of anti-seismic Reinforced Concrete (R/C) walls on buildings with the use of Special Anti-seismic Steel Elements (SASEs), which provide additional stiffness as well as absorption of seismic energy.
This project suggests a new connection device of these elements (SASEs) with the R/C frame, that provides control of the forces that are developed at the diagonal Steel rods, ensures (protects) from possible failure of the R/C frame and simultaneously absorbs the seismic energy. The proposed devices, named CARs (Control, Absorption, Restrain Steel Elements), have the ability to retain the plastic displacements to a desired level. Inelastic analysis by the procedure of PushOver until structural collapse and also quasistatic analysis using cyclic loading were carried out. The obtained numerical results point out the effectiveness of the suggested device.

KEYWORDS: Anti-seismic, Steel Elements, Devices, Control, Absorption, Restrain

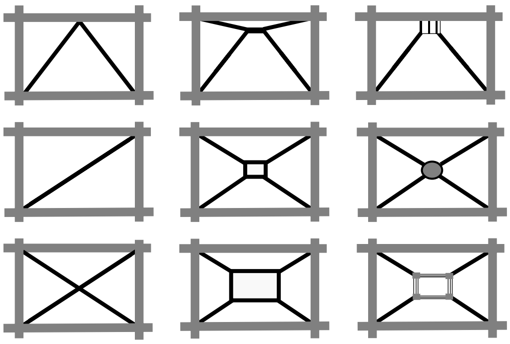
1. INTRODUCTION

A large sector of developments in the anti-seismic strengthening of constructions concerns the placement of Special Steel Anti-Seismic Elements. This new approach has been tested and used in several countries and applications till now have proved its large potentials in the anti-seismic designing of new, as well as in retrofitting existing buildings. The main advantage of these elements is that they absorb seismic energy and render the expected seismic damage predictable and easy to repair.

2. STRENGTHENING OF BUILDINGS WITH SPECIAL ANTI-SEISMIC STEEL ELEMENTS (SASEs)

Research in the sector of anti-seismic strengthening of the superstructure of buildings has led to the development of a variety of methods for the anti-seismic strengthening of building with additional Steel elements (Bergman M., 1987, Marioni A., 1999, Chang C.,1993, Tremblay R,1993, Nims K.,1993). The proposition for a random placement of SASEs within the RC frame is fundamental and offers important improvement to the seismic behavior of the building (Papadopoulos, 2002).

We may classify these type of anti-seismic strengthenings in 3 categories:
1. Concentric strengthening diagonal steel elements. (Only axial forces are developed on the diagonal elements (Figure 1a).
2. Eccentric strengthenings with plastic behavior. Bending, moments at a properly selected area (Figure 1b). also act at the SASEs
3. Strengthenings which include devices of passive energy diffusion (Figure 1c).



(a) (b) (c)

Figure 1. Forms of Special Anti-seismic Steel Elements (SASE$_S$)

The use of concentric diagonal steel elements without plastic behavior and without energy diffusion devices has the following important disadvantages:

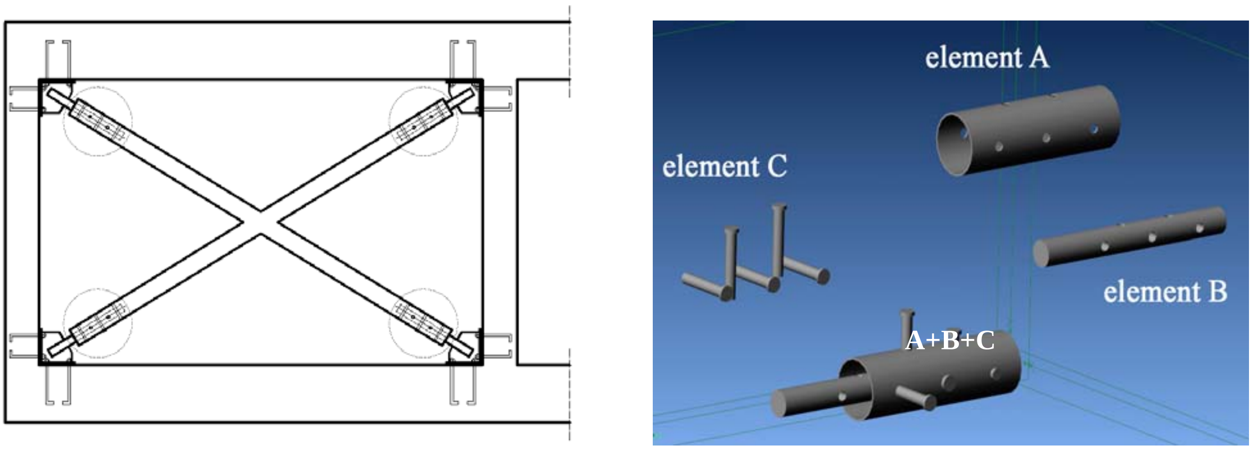
- Risk of early failure of the diagonal element (due to either tension or compression-buckling).
- The rigidity of the structure increases; a fact that has as a consequence smaller natural period and activation of larger seismic loads for the expected earthquakes .
- The available ductility of the R/C frame structure is not exploited.

The above disadvantages of simple steel diagonal strengthenings may be handled as follows:

1. By the proper designing of the strengthening devices in order to acheive the desirable flexibility and plasticity (Jurukovski D., 1988, Ciampi V., 1993, 1995, Saeid Sabouri-Ghomi, 2005 (Figure 1b).
2. By the addition, at a suitable position, of appropriate simple energy absorption devices (Figure 1c).. The devices that have been developed till today may be classified as yield and friction devices. (Bergman M., 1987, Marioni A., 1999, Chang C.,1993, Tremblay R, 1993, Nims K., 1993).

3. PROPOSITION FOR A NEW DEVICE

A new device is presented in this project. Its aim is to Control the forces that are developed on the diagonal elements, Absorb seismic energy and Restrain the possible undesired displacements. The suggested device CAR (Control, Absorption, Restrain) is inserted at the connection points of the Steel diagonal members and the plates that are rigidly connected to the junctions of the R/C frame(figure 2a).



(a) (b)

Figure 2. Arrangement and parts of CAR device

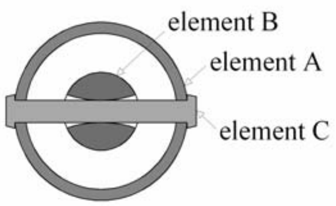
The parts that the device consists of (Figure 2b) are:

- Element A, exterior tube
- Element B, interior Steel shaft and
- Element C, Traverse elastoplastic regulation bolts

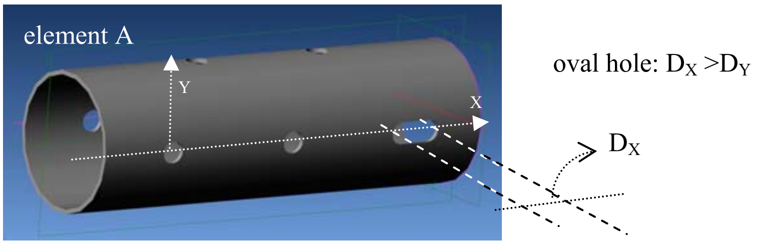
The relevant movement of elements A and B is carried out by a simultaneous elastoplastic bending deformation of the bolts that connect crosswise elements A and B. The number of bolts and their elastoplastic characteristics define the principle of elastoplastic behavior of the diagonal bars on an axial load.

Figure 3_a shows the details of the bolt hole at Element B. The diameter of the hole is gradually expanded in order to contribute to the increase of the free length of the bending function of the bolt and the increase of the final plastic displacements.

There is also a provision for a Restrain bolt (stoppage bolt). This bolt is made of high yield Steel, and can slide inactively through an appropriately selected oval hole at element A (figure 3_b).



(a)



(b)

Figure 3: CAR device – Construction details

As a result, the activation of this bolt is carried out at a "second time" and it allows the desired plastic deformations of the deforming bolts to take place. The activation of the stoppage bolt allows the transfer of an additional axial load from elements A to element B of the device. An appropriate configuration / geometry in the area of the stoppage bolt (oval hole) eliminates any additional compression forces on the diagonal elements and allows only tensional forces to be developed.

3.1 The elastoplastic bolt behavour

The objective here is to predict the behaviour of a single bolt under quasistatic cyclic loading. The bolt is considered clamped at the ends carrying a central line load (see figure 3a). The maximum deflection at the center of the bolt in conjunction with the value of the applied load and obtained stresses are the criterion for the selection of the proper bolt.

The elastoplastic behavior of the bolts is examined through finite element micro models. The bolts are circular in section with diameter D and fabricated by using low yield Steel of the following characteristics:
Elastic Modulus 210GPA
Initial yield stress :160 MPA
Ultimate stress capacity 280MPA
Ultimate strain 40%

For the analyses, the computer program ADINA was used. The bolt is discretized through a mesh of 4000 8-node 3D-solid elements. Plastic multilinear material model was used, based on the Von Mises yield condition and kinematic hardening rule under cyclic load. A large displacement – large strain formulation was used. A bolt of 24mm diameter was finally selected, which provided good characteristics for the connection of the diagonals with the examined frame. The force-deformation relation at the central section of the bolt (figure 4a,b) provided the information for the characteristics of the special elements, used to simulate the response of the bolts placed at the

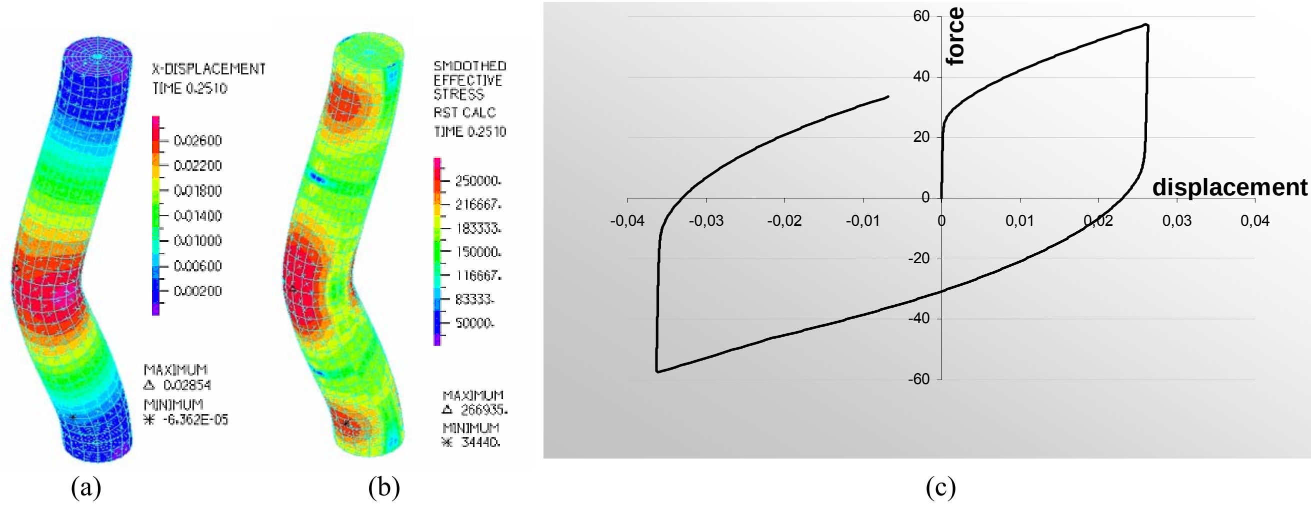


Figure 4 The force-deformation relation at the central section of the bolt under cyclic loading

end of each diagonal at the finite element macromodel of the structure. The distribution of the effective stresses and displacements at the bolt, for a total force value of 58kN, are shown in figure 4c.

3.2 Modeling of the structural system

The finite element model of the structure was solved by using the program SAP2000. The proposed connection of the rods to the R/C frame is simulated by a macro model of two parallel NLLINK elements that the program provides. The PLASTIC element will be used for the modeling of the elastoplastic bolts and the HOOK element for the stoppage bolt. PLASTIC and HOOK have non-linear qualities, as shown in figure 5.

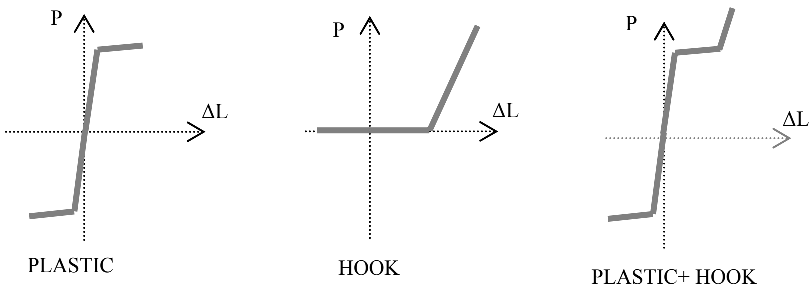


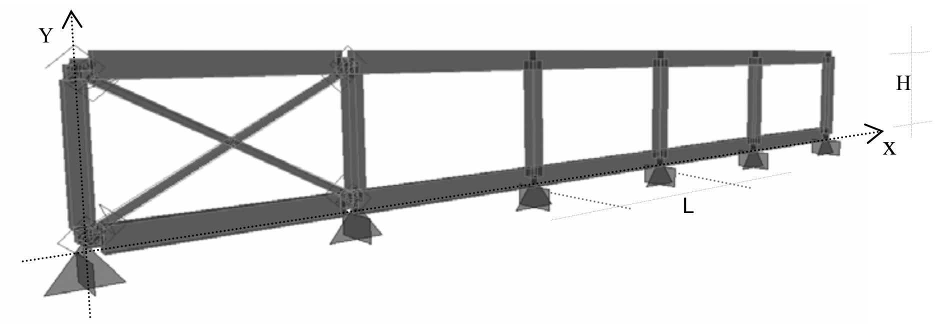
Figure 5 Modeling of the frame-rod connection

The response of the SAP2000 macro model of four bolts under cyclic loading was found to be in a very good agreement with their “exact” response given by the micro model of ADINA .

4. STUDY OF A R/C FRAME WITH SASEs and CAR devices

The plane frame of figure (6) was chosen as basis of the analysis . Nonlinear static analysis with incrementally increased lateral loading (pushover analysis) was performed. The solution proceeded until the program failed to converge. For all the analyses it was checked that the failure of convergence expressed structural collapse. Nonlinear dynamic analyses using quasistatic cyclic loading were performed as well. The seismic behavior of the system depends both on the characteristics of the bare frame as well as of the SASEs.

The Nonlinear static Pushover Analysis is carried out by the SAP2000 program, considering that the probable points of plastic hinges are the ends of the elements. For the R/C frame, moment –rotation hinge properties are used for the beams and the coupled interacting P-M (axial force-moment)-rotation hinge properties are used for the columns.
For the steel diagonals axial force- displacement hinge properties are used, while the modeling of the connection of the rods to the R/C frame the PLASTIC and HOOK elements are used.



Given:
L=4,5 m   H=3,0 m

(α) frame structure
Columns: 30/30 (8Φ14)
Beams: 25/50 (3Φ14 / 3Φ12)

(β) SASE
Diagonal D=100mm, t=4,35mm

Figure 6 The structural system

The influence of the insertion of the CAR device (Control, Absorption, Restrain) between R/C elements and Special Steel Anti-seismic Elements is presented. Two variations were studied in relation to the way of fixing the SASEs:

1. Classic fixed connection where the activation of the Special Steel Anti-seismic Elements is direct with equal displacements of the nodes of the R/C structure and the Steel diagonals.
2. Insertion of the suggested CAR device on the connection of the SASEs with R/C elements. In this case, compressive or tensile forces on the connection points of the SASEs and the frame are developed, according to the number of bolts and their elastoplastic characteristics.

4.1 The results of the analyses

In the following the graphs of the horizontal displacement of the top beam versus the total shear force at the base of the structure, as obtained by the PushOver analyses are presented. Also the axial forces of the diagonals versus the horizontal displacement of the top beam for the most characteristic cases are shown.

4.1.1 *The R/C frame*

After the size and the reinforcing of the R/C members have been chosen the PushOver analysis which was performed gave maximum base shear before collapse 320kN under ultimate horizontal displacement at the top 52 mm. (figure 7)

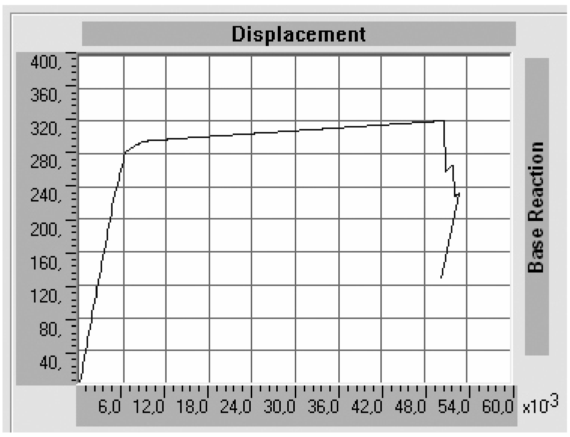


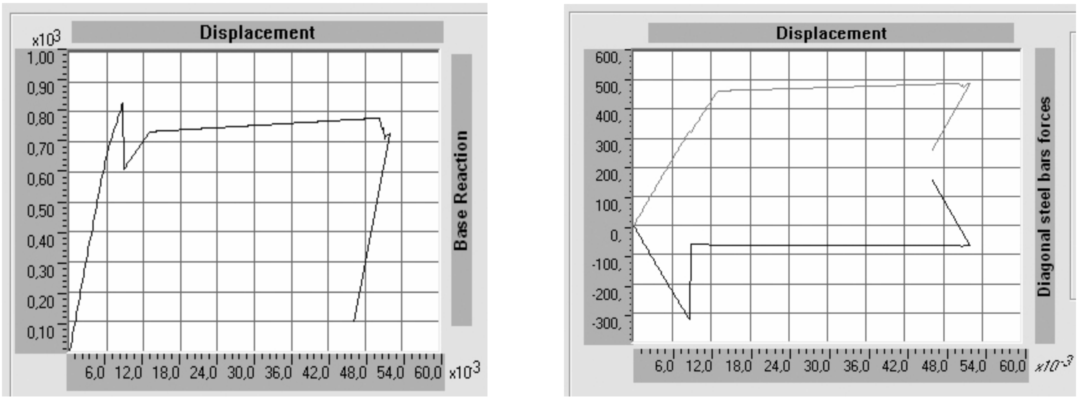
Figure 7: Base shear force versus top beam horizontal displacement of the bare frame

It was chosen that the disired strength of the system (the R/C frame and the Special STEEL Anti-seismic Elements) would be twice the strength of the bare frame. That is the ultimate base shear would be 600 kN. ($Q_{FR+SASEs} \approx 600$ kN). Under this assumption the section of the diagonals was obtained.

Two variations in relation to the way of fixing the SASEs were studied via PushOver analyses:

4.1.2 Classic fixed connection of the R/C structure and the Steel diagonals

It is observed (figure 8) an early failure of the diagonal under compression due to buckling as well as yielding of the diagonal under tension for horizontal displacements at about 20% of the ultimate displacement of the bare frame.



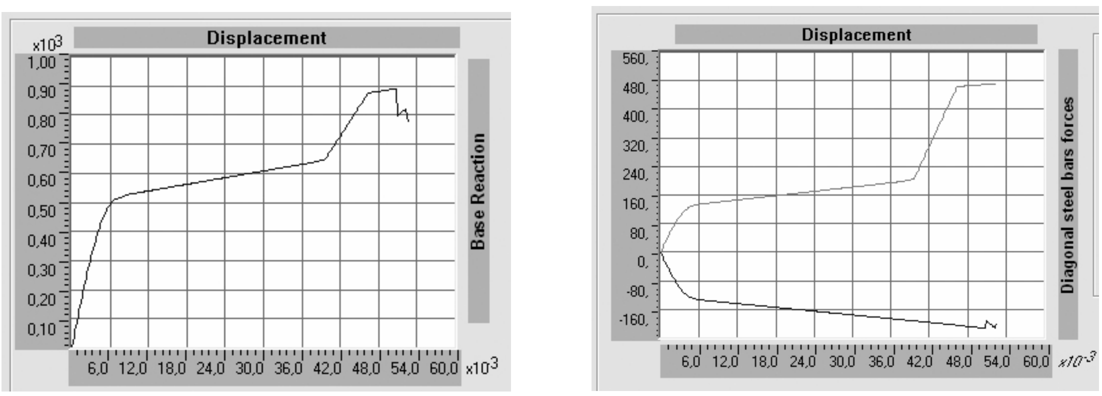
(a) (b)

Figure 8: Classic fixed connection: Graph of horizontal displacements versus
(a) total base shear force (b) axial forces of the diagonals

4.1.3 Connection of the R/C structure and the Steel diagonals via the CAR device

The analyses of the CAR devices were based on : (a) PLASTIC NLLING element, stiffness=500000 kN/m and yield =180 MBA and (b) for HOOK NLLING element span open=0,015m

It is observed (figure 9) that the early failure of the diagonal under compression due to buckling was prevented and the available ductility of the system was fully developed. The activation of the restraint bolt, before the horizontal displacements reach the ultimate values obtained for the bare frame prevent it from serious damages.



(a) (b)

Figure 9: The system (connections with CAR). Graph of horizontal displacements versus
(a) total base shear force (b) axial forces of the diagonals

In figure 10 the quasistatic cycling load versus time for which the time history analyses were performed is presented. In figure 11a is presented the variation of the total shear force at the base of the structure versus the horizontal displacement of the top beam and in figure 11b is presented the variation of the axial forces of the diagonals versus the horizontal displacement of the top beam. It is observed that the SASEs operate under safe conditions.

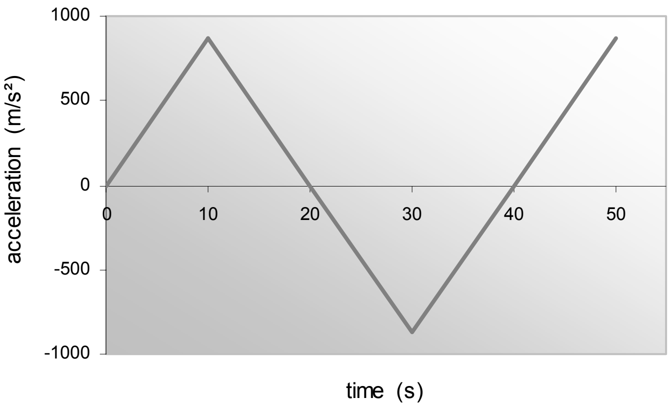
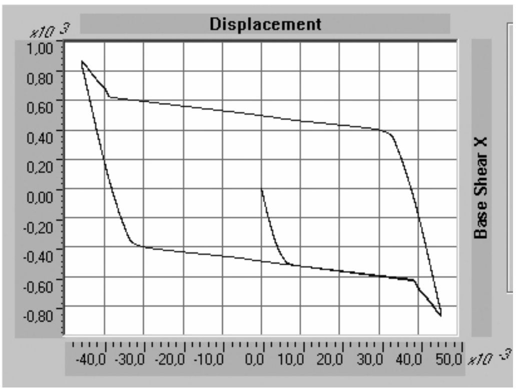
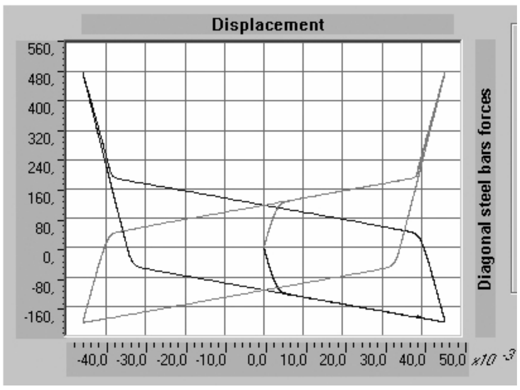


Figure: 10 Load – time diagram

The hysteretic loops of the horizontal displacement represent the amount of the absorbed energy. At the graph of the axial forces versus displacements it is also obvious the sustenance of the displacements via the activation of the diagonal which is in tension.





(a) (b)

Figure 11 The system (connections with CAR). Hysteretic loops (a) base shear (b) diagonal steel bar

5. CONCLUSIONS

The advantages that result from the replacement of the anti-seismic walls with the Special Anti-seismic Steel Elements, if properly designed, are signifigant and may lead to more inexpensive and safe structures.

The connection of the Special Anti-seismic Steel Elements to the R/C frame have a better behaviour (avoidance of early buckling and good plastic behavior) only if they the properly designed. This proposition is directed towards this goal.

The analyses carried out proved that the insertion of the proposed CAR devices :

- Controls / adjust the level of stresses (forces) that will be developed on the diagonal rods.
- Absorbs seismic energy.
- Restrains / stops the plastic displacements at the desirable level (before failure).
- Contributes to the avoidance of an early failure due to compression (buckling).
- Increases the available ductility of the system.

In general, as the micro model analysis with ADINA showed, the selection of the proper number of bolts and their elastoplastic characteristics may give the required flexibility to the system (the R/C frame and the Special STEEL Anti-seismic Elements) in order to achieve the best seismic behavior.

The optimum opening for the restrain bolt is open for study. The restrain bolt must be activated before the appearance of any serious damages at the R/C frame.

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