Paper No. 1456. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3
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STRUCTURAL PROJECT OF THE REINFORCEMENT OF TWO BUILDINGS WITHOUT SEISMIC DAMAGES

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ABSTRACT

After the occurrence of major earthquakes it has been common in Mexico to increase the seismic capacity of the future and damaged buildings. Nevertheless, there are many existing undamaged constructions that for many different reasons have to be reinforced. In these cases the solutions have to combine many factors, such as the need to continue the use of the building while the reinforcement is constructed, the cost and the serviceability of the renewed construction. It is better to have a "new building" than a "reinforced one". In this paper two cases are presented, in which the "normal" reinforcing methods were not acceptable for the owner and a combination of architectonical, structural and soil-mechanics aspects were made to fulfill his interests.

KEYWORDS

Seismic reinforcement; structural upgrading.

INTRODUCTION

After the 1985 earthquake the seismic requirements in the Mexico City Code were substantially increased. In the soft clay zone the actual seismic coefficient is 0.4g, in comparison to the former value of 0.24g of the 1976 Code. This coefficient may be divided by a "seismic behavior factor", Q, similar to the "Rw" defined in the American UBC code, which depends on the ductility characteristics of the structure, having values of 4 for the special moment resisting frames and 2 for less ductile systems. In the previous code (1963) the coefficient was a reduced one, in which the ductility of the structural system was implicit, with a value of 0.06g. Before 1957 the code requirements were minimal, with a 0.025g seismic coefficient. Nevertheless, for some Mexican engineers it was obvious that this value was not correct, and taking in consideration the state of the art studies in the U.S. universities they preffered to use a value of around 0.05g.
New constructions and any reinforcement to damaged buildings have to be designed according to these standards. The code states that undamaged structures do not need to be upgraded. Nevertheless there are

some buildings that, according to the owner or user's request, have to be reinforced in order to match the new service and resistance code requirements. In cases like these, the best solution consists of the combination of many factors, even the need of continous use of the building while the reinforcement is done. It can be a real engineering challenge to achieve all this.
In this paper two examples are presented, where many previous alternatives, developed by other engineering firms, were found not to be satisfactory to the owner and other solutions had to be found.

BUILDING A

This structure (Fig.1) was projected for housing in 1950 and built in 1951-1953. It occupies the total of a trapezoidal shape lot, with maximum dimensions of 23.7 x 26.8m., having one underground level, one grade level, eleven floors plus the elevator machinery level. The structure consists formed of concrete frames, with columns, main and secondary beams and solid slabs. The original foundation is a partially compensated one, with a shallow concrete box of about 2m high below the underground level, having therefore a compensation of 5m in relation to the street level. As is normal for these type of buildings, the partition walls were of masonry.
Through the years this structure suffered no structural damage to the frames, but a lot of non-structural problems, such as crackings in the walls and broken windows.
The new owner wanted to change the use to an office building with open spaces, but with the structural capacity defined in the actual code.
In initial studies made by other designers it was concluded that, taking into account the lateral forces capacity of the construction, seven stories had to be demolished in order to avoid reinforcement. In the case of keeping the same office space, the reinforcing would consist of the following: increase the section of all beams and 60% of the columns and include a perimetral steel X bracing. None of these alternatives was considered acceptable by the owner.
After a review of the problem it seemed logical that the solution had to be focused in avoiding any "damage" to the existing construction, as it was in good shape and able to carry the dead and live loads, and some part of the lateral ones. So, a perimetral reinforcing was supposed to be the best alternative, although it could lead to a foundation problem.
As the existing structure would carry seismic effects and did not have the detailing that is necessary for being considered ductile, a low value for Q=2 was used. In general numbers, as the actual reduced seismic coefficient is 0.20g and the original one was 0.05g, the stiffness of the reinforcement had to be about three times higher than the original, in order to avoid any interior upgrading. Also, the structural work of the additional structure had to be similar to the existing one. For these reasons a concrete structure, with large columns and beams was decided.
The next problem was the foundation because of the heavy weight of the reinforcement and the increased seismic effects. Here two aspects were considered. The first one was the reduction of the dead load because the interior masonry walls would be retired, and the second one, related to the soil conditions. Laying the structure for more than 30 years on soft clay, an increase in the bearing capacity could be expected due to the consolidation and the pumping effect of the inferior layers.
A soil mechanics study was performed and compared to the original one. It was found that the actual conditions of the soil were better, having an additional bearing capacity of 20 to 25 %. The result was that, taking into account these two factors, the reinforced structure was heavier than the original but the additional bearing capacity of the soil could support it according to code regulations.
An additional advantage was the fact that the position of the new columns coincided, almost in each case, with the perimeter retaining wall, having therefore a very high stiffness.
After making the tridimensional analysis, design of the reinforcement and review of the capacity of the existing sections, it was found that the whole system worked. The technical information of the initial building and the actual one is shown in table form after the conclusions.

The reinforcing was finished in late 1994, matching the time and cost schedules. The vertical movement registers (Fig.3) show that the performance of the structure has been according to the expectations and the aspect of the building is of a new one.

BUILDING B

This is an office building that was projected and constructed in 1956 (Fig.3). It had a rectangular shape in plan, 16.2m wide and 59.4m long, with a total height of 50.7m . On one side it had a communication with a 6 story building and on other with a 20 story lateral construction, all these on the same lot. It has one underground level, the ground level, 11 type floors, one roof level and machinery level. The first floor is 4.6m high and the rest are 3.5m .

The structure was made of reinforced concrete frames. The foundation was formed by a concrete box on point bearing driven piles, with a square section of 50cm. The number of piles was 294.

The initial studies for the reinforcement of the building, developed by different engineering firms, brought the following alternatives: demolition of several floors; an increase in the sections of beams and columns; a combination of both criteriae; to keep the actual construction by incorporating perimetral steel X bracing; increase the column sections with concrete and add steel bracings; to build concrete shear walls in the short direction and interior shear walls in the long direction connected with beams; reinforce some frames with steel sections and to build concrete shear walls in the exterior of the short direction. In most of the alternatives the reinforcement of the foundation was needed, by the addition of piles.

In this case, it was stated by the owner that the building needed to be on use while the construction was made.

The building did not have any structural damage, having only the "normal" non-structural problems in partition walls caused by the earthquakes because of its low lateral stiffness.

One particular situation was that the construction is located in the interior of the lot, having lateral space on all sides, except where it was connected to the 6 story building. For this reason an exterior construction was possible. Because of stiffness problems in the short direction it was more necessary to increase the capacity in that direction. The combination of all the indicated factors led to the following solution: construction of 4 exterior sections, 5.6m wide and 16.2m long, located close to the corners of the existing building, made with concrete columns and beams in the long direction, and macro-frames in the short direction, formed with columns, normal beams and big beams, one story high, every 3 floors. There were four frames, two located on the exterior of the building and two in the interior, which were the only internal constructions. To link the existing construction to the reinforcement some demolishing of the perimeter beams was needed, and also the welding of new rebar to the existing slab. The new areas increased the office space in almost 4,000m2. Because of the additional weight and for carrying the seismic effects the foundation of the reinforcement was projected with piles. The number of them was of 156, with the advantage of driving them with normal procedures, as all were located on the outside of the existing building.

The project needed to be changed when an architectural firm was hired for the development of the façades and details. An emergency exit was included at one side and also some exterior elements tying the additional construction at roof level in both sides in the long direction.

The construction started early in 1995 and is scheduled to finish early in 1996.

During the earthquakes of Sept.14 and Oct.9 1995 the reinforcement was up to the fifth floor. No damage resulted from the ground to that level, but in the upper ones some crackings in the partition walls were found.

In this case the stiffness of the reinforcement is much higher than the original structure. Therefore the forces that have to be carried by this are lower than before, nevertheless the base shears are more than 4.33 times higher.

In table form the technical aspects of the seismic analysis are presented.

Technical information of Building B.

STRUCTURE	ORIGINAL STRUCTURE	REINFORCED STRUCTURE
Weight [ton]	**W**=11,277.5	**W**=18,949.5
Seismic coefficient	**c**=0.05g	**c**=0.40g
Seismic behavior factor	Included in the coefficient	**Q**=2.0
Seismic base shear [ton]	**Vsx**=550.9 **Vsy**=547.9	**Vsx**=2,386.4 **Vsy**=2,342.7
Fundamental period [seg]	**Tx**=2.136 **Ty**=2.696	**Tx**=0.526 **Ty**=0.602
Lateral desplacement at 12th level **H**=43.1m [cm] * (multiplied by Q)	**Dx**= 9.89=0.0023**H** **Dy**=16.65=0.0039**H**	***Dx**=3.46=0.0008**H** ***Dy**=5.20=0.0012**H**
Base shear carried by the reinforcement [ton]	---	**Vx**=2,252.2=94.4%**Vsx** **Vy**=2,223.7=94.9%**Vsy**

FOUNDATION	ORIGINAL STRUCTURE	REINFORCED STRUCTURE
Contact area [m^2]	**A**=962.3	**A**=1,338.1
Total weight at foundation level [ton]	**W**=14,650.1	**W**=23,686.5
Seismic overturning moment (80%) [ton·m]	**Mvx**=14,999.8 **Mvy**=14,711.0	**Mvx**=68,978.2 **Mvy**=66,501.4
Stresses at the soil in the Y direction [ton/m^2]	$q_{máx.}$=22.29 $q_{mín.}$=8.15	$q_{máx.}$=35.06 $q_{mín.}$=0.34
Stresses at the soil in the X direction [ton/m^2]	$q_{máx.}$=16.91 $q_{mín.}$=13.53	$q_{máx.}$=22.01 $q_{mín.}$=13.39
Number of piles	No.=294	No.=450
Average load per pile [ton]	**P**=49.8	**P**=52.6

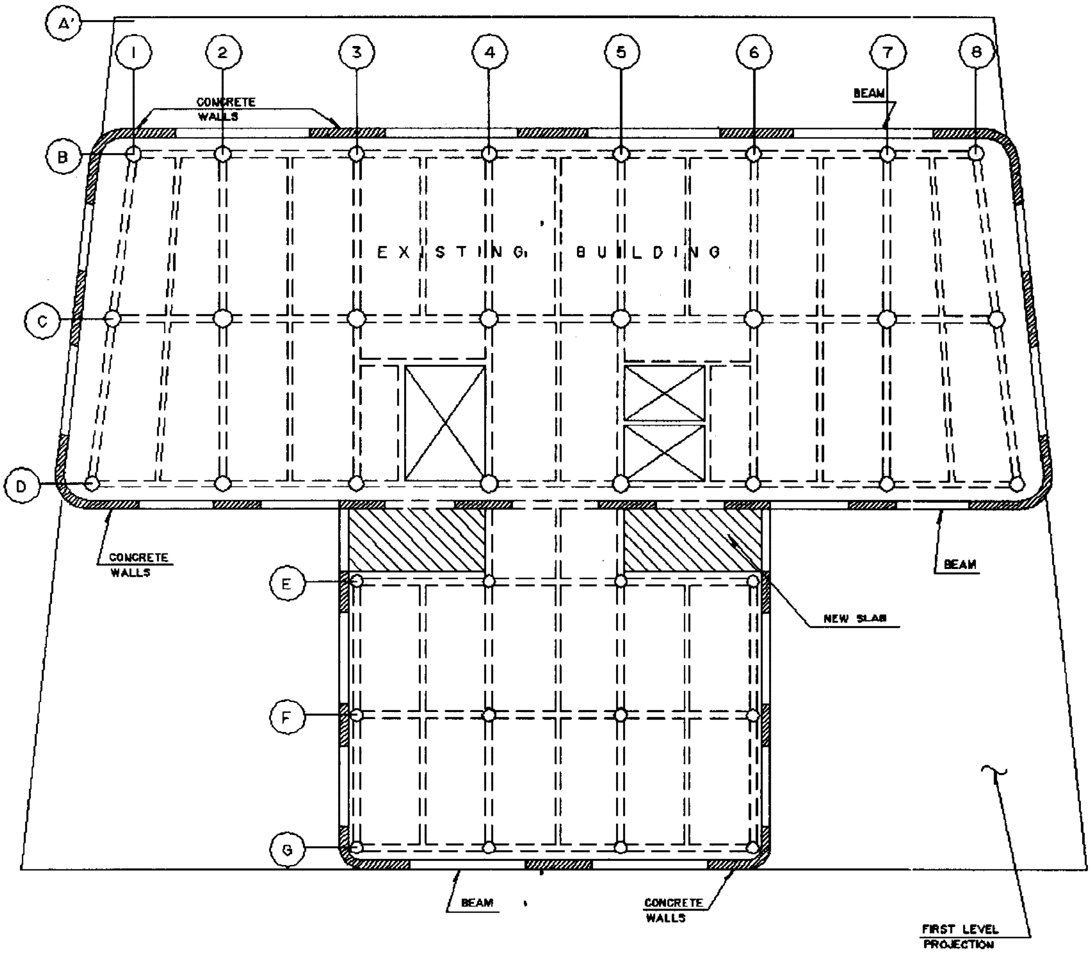
CONCLUSIONS

The general conclusions of this work are the following:
1. To comply with the increasing requirements of the construction codes, many factors have to be considered to find the best solution.
2. Although some generally accepted procedures like the increase of the sections, steel X bracings or concrete shear walls, are technically acceptable, it will be a better solution to have a non visible reinforcement.
3. If the idea is to increase the capacity of a structure it is better to add a new one, combined with architectonical aspect and arrive at a "new building", that will not give the impression to be damaged before.
4. In soft clay zones it is possible to use the advantage of the improvement in its capacity through time.

Technical information of Building A.

STRUCTURE	**ORIGINAL STRUCTURE**	**REINFORCED STRUCTURE**
Weight [ton]	**W**=4,847.7	**W**=5,978.2
Seismic coefficient	**c**=0.06g	**c**=0.40g
Seismic behavior factor	Included in the coefficient	**Q**=2.0
Seismic base shear [ton]	**Vsx**=200.6 **Vsy**=204.1	**Vsx**=1,013.7 **Vsy**=1,019.7
Fundamental period [seg]	**Tx**=2.470 **Ty**=2.603	**Tx**=1.029 **Ty**=1.305
Lateral desplacement at the 11th level **H**=36.06m [cm] *(Multiplied by Q)	**Dx**=11.73=0.0033**H** **Dy**=13.30=0.0037**H**	***Dx**=19.64=0.0054**H** ***Dy**=14.30=0.0040**H**
Base shear carried by the reinforcement [ton]	---	**Vx**=814.8=80.4%**Vsx** **Vy**=781.5=76.6%**Vsy**

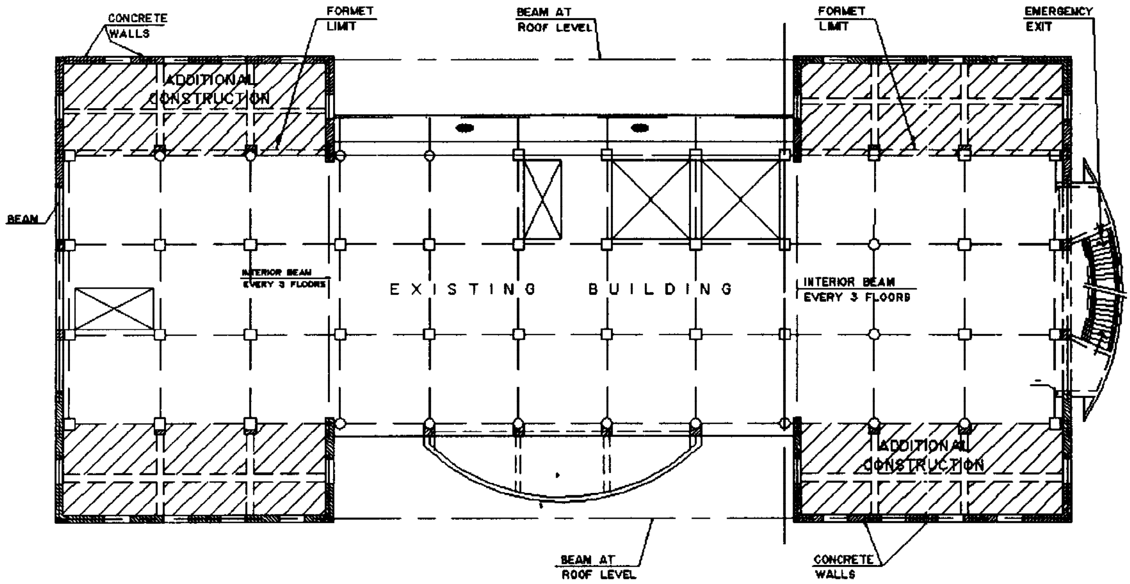
FOUNDATION	**ORIGINAL STRUCTURE**	**REINFORCED STRUCTURE**
Contact area [m^2]	**A**=699.5	**A**=699.5
Weight at foundation level [ton]	**W**=7,227.3	**W**=8,883.8
Seismic overturning moments (80%) [ton·m]	**Mvx**=4,167.6 **Mvy**=4,049.4	**Mvx**=22,089.0 **Mvy**=22,068.0
Stresses at the soil in the Y direction [ton/m^2]	$q_{máx.}$=13.98 $q_{mín.}$=6.68	$q_{máx.}$=22.96 $q_{mín.}$=2.44
Stresses at the soil in the X direction [ton/m^2]	$q_{máx.}$=13.68 $q_{mín.}$=6.98	$q_{máx.}$=22.29 $q_{mín.}$=3.11



GENERAL PLAN

BUILDING A SCALE 1 : 202.6

FIG. 1



GENERAL PLAN

BUILDING B SCALE 1 : 416

FIG. 2

Original

Actual

BUILDING A

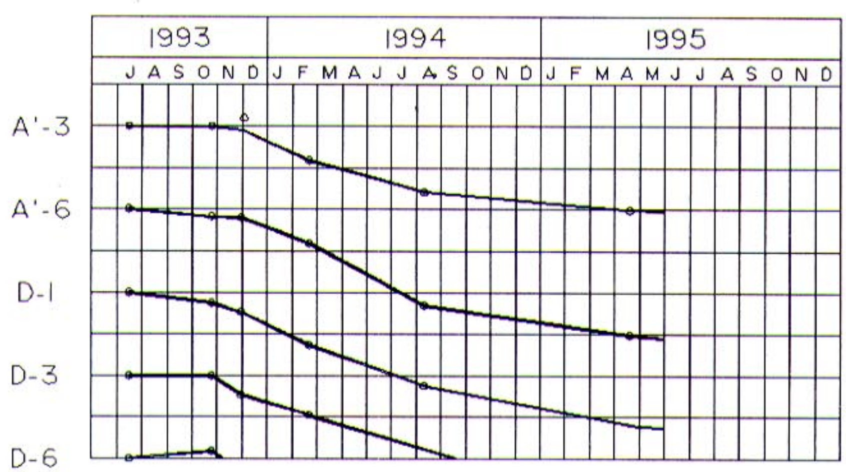


Fig.3 Vertical movements in some points

Original

Actual (January 1996)

BUILDING B