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TWELVE GOLDEN RULES of EARTHQUAKE RESISTANT DESIGN

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ABSTRACT :

The main purpose of this presentation is to introduce twelve golden rules of structural design, in order to achieve earthquake resistant design. These golden rules include recommendations ranging from the selection of a suitable lateral load carrying system to eliminating the vertical and horizontal structural irregularities such as torsion, soft storey, short column and pounding.

Measures of protection are supplied from heavy weight concentrations, such as bulky façade elements; massive earth fills at roofs and canopies envisaged for growing green plantations; roof level swimming pools etc. Recommendations are also supplied to take necessary measures and also to prevent soil and structural failures due to **a)** large settlements and/or liquefaction, **b)** soil amplification etc.

Keywords : Golden rules, irregularities, amplification, liquefaction, short column, soft storey.

1. INTRODUCTION

A set of twelve 'golden rules' has been recommended in order to achieve practically 'earthquake resistant' design. These golden rules are actually the summary of practical advices extracted from the observation of structural damages occurred to a variety of buildings during the recent destructive earthquakes. These twelve golden rules may be summarised as follows :(†)

01. Prefer shear wall and box type structural systems instead of moment resisting frames. Your structural system must preferably be uniform, regular and symmetrical in plan and in elevation (M).

02. Try not to allow any degree of torsional irregularity (M).

03. Never allow unduly heavy weight concentrations at any part of your building (M).

04. Do not allow heavy facade panels or unduly heavy beams or structural elements (M).

05. Design your beams and columns at a connection in such a way that the sum of the ultimate bending moment capacities of columns in a particular direction of earthquake, should be twenty *(20 %)* percent greater than the sum of rupture bending moment capacities of the beams. *(Stronger column criterion)*, (S, M).

06. Do not allow 'short' columns ! (M).

07. Do not allow weak and /or soft storey (M).

(†) The letters (M), and (S) existing at the end of each golden rule, indicates whether that particular structural irregularity exists and therefore must be eliminated by the Architect – Mimar **(M)** or the **(S)** Structural Engineer.

08. Do not allow the pounding of two adjacent buildings (M).

09. Do not allow the columns to be seated (supported) at the end of cantilevers or at midspan of beams.

10. Analyse carefully and conscientiously, the possibilities of **a)** Soil amplification at layered soil strata, and **b)** Soil liquefaction.

11. Utilize appropriately heavy and tight confinement ties (lateral reinforcement) within the top and bottom confinement zones of columns, as well as within the beam – column junctions (S). Use ordinary reinforced concrete covers (mantle), having an approximate thickness of about *20 cm* or *25 cm* all around the periphery of the steel profile columns, in order to provide additional rigidity (strength) as well as protection against fire and corrosion. This particular composite section is referred as 'Japanese Miracle'. Because, no steel building, strengthened by such reinforced concrete mantles, ever suffered a minor crack during the 17.1.1995 Kobe Earthquake of M = 7.2.

12. In order to achieve a performance stage characterised as 'the immediate occupation' utilise seismic isolators at the base, and / or seismic viscodampers as bracings at upper elevations (S, M).

2. CLASSIFICATION OF DAMAGE CATEGORIES

The reasons of damage to structures, during a severe earthquake, may be categorised into four essential groups as follows :

2.1 Damages due to soil failures

Faulting, foundation settlement, subsidence, sliding and lateral spreading, as well as tsunami waves are within this category of failures. These should be adequate and appropriate soil investigation in order to predict as well as to prevent such soil failures.

2.2 Damages due to erroneous (faulty) architectural design

- Columns seated at cantilevers, or at midspan of beams,
- Atriums, large slab openings,
- Large projections or holes in a slab,
- Torsional irregularities,
- Undesirable selection of lateral load carrying system,
- Soft (weak) storey,
- 'Short' columns,
- Heavy façade elements,
- Unduly heavy slabs, ornamental parts and / or panels,
- Probability of pounding,

2.3 Damages due to design mistakes

'Weak' or 'short' columns, violation of ductility requirements in beam and column sizes and reinforcement.

2.4 Damages due to ignoring the following special recommendations

- Seismic base isolators for low rise buildings,
- Visco - dampers at superstructure,
- Japanese miracle in steel structures,

A variety of photographs are supplied in this presentation illustrating typical soil failures and structural damages as classified in the preceding Section.

3. LIQUEFACTION

Some major land slide, fault displacement, dam failure and also soil liquefaction examples are illustrated in *Figs. 1* to *2*. Some fundamental recommendations are given below in order to prevent such soil failures:

3.1 Microzonation maps

The microzonation maps, showing the land slide and liquefaction susceptible zones in a municipal area help to prevent the occurrence of such disasters. Unfortunately, **only four** municipalities in Turkey *(Istanbul, Izmir, Bursa and Eskisehir)* prepared such microzonation maps so far *(2013)*.

3.2 Detailed field and laboratory survey

Detailed field, laboratory and also office surveys must be conducted as required by the modern Building Codes, such as **UBC – 1997** *(2 pages)*, **FEMA 273 – 1997** *(3 pages)* and **Eurocode 8-1998** *(5 pages)*. Unfortunately, there is only one sentence requirement in the current Turkish earthquake code *(TDY 2007, Article 6.2.2)*. The Turkish earthquake code, must be revised immediately, to include detailed field and laboratory investigations as already required by the modern Building Codes of the USA and Europe.

3.3 A major handicap and loophole !

Unfortunately, no soil investigation is necessary by the current Turkish Earthquake Code *(TDY – 2007)* for a building unless it is;

- **a)** Higher than *60 m* in total height, or,
- **b)** A school, museum or hospital with an importance factor of $I \geq 1.4$.

The local soil information if available, or visual observational data would be sufficient for such buildings. It is absolutely a pity and misfortune that the current Turkish Earthquake Code, **does not require** any soil report based on detailed field and laboratory investigations, for residential and industrial buildings, for sport facilities, theaters, concert halls, shopping centers and hotels, lower than *60 m* in height. Such a vital deficiency must be corrected as urgently as possible. Unfortunately, the writer have been consistently advising the Ministry of Public Works *(The Ministry of Environments and Urbanisation)* in writing, since 2007 **[6 ~ 8]**. But, no corrective measures have yet been taken *(June 2013)*.

4. SOIL AMPLIFICATION

4.1 Amplification during the Gediz earthquake

An internationally recognized case study for the soil amplification is the collapse of the paint workshop buildings at the Tofas automobile factory in Bursa, Turkey during the March 28, 1970 Gediz earthquake *(M = 7.1)* as already discussed in detail by *Tezcan, Seed, et. al* **[5]**. The damaged building, the paint workshop, at the Tofas automobile factory in Bursa, is located 145 kilometer away from the epicenter of the Gediz earthquake as shown in *Figs. 3* and *4*. The ground acceleration at the epicentral area was on the order of $a = 0.25g$. However, it decreased to a level of $a = 0.01g$ after travelling *145 km* distance from Gediz to Bursa valley.

The earthquake waves however increased their acceleration amplitude by about 5 (*five*) times, from *0.01g* to *0.05g*, while travelling from the base rock to the ground surface at Bursa, by means of refraction and reflection process through the stratified soil layers. Thereby, the maximum ground acceleration reached to a high level of $a = 0.05g$ at the site of Tofas automobile factory.

The predominate period of vibration of the soil at Tofas automobile factory was measured as $T_0 = 1.25$ *seconds*, during an accidental aftershock record taken while we were just inspecting the damaged building at the site. The fundamental period of vibration of the damaged paint workshop was also calculated to be

exactly $T_1 = 1.25$ seconds in the computer. The building consisted actually, one storey portal frames 6 meter apart from each other, with $L = 12\ m$ and $H = 5\ m$, supported by *30 cm / 50 cm* reinforced concrete columns, with a concrete quality of *C20 MPa*.

It is therefore seen that there was an unusual phenomenon of soil amplification, about five times, while travelling from base rock to ground surface. A further amplification of response, on the order of 5 (*five*) times again occurred, during the response of the building to the earthquake waves, from the base to the roof.

4.2 Amplification during the Kocaeli earthquake

It is seen in *Fig. 5* that the ground accelerations reached as high as $a_g = 0.25g$ at the Ambarlı thermal power plant located at Avcılar, in the west of Istanbul, nearly *150 km* away from the epicenter. Similar amplifications were also recorded at the Petrochemical center at Derince and also at the Yesilkoy Ataturk airport in Istanbul.

5. IRREGULARITIES ALONG THE HEIGHT

The current Turkish earthquake code, *TDY 2007*, does not permit any column or shear wall to be discontinued at ground floor level as already indicated in *Fig. 6*. It is strange and awkward, as well as a pity, however that a column may be allowed to be discontinued at ground floor or at any floor level above, and may be allowed to be carried at the midspan of any beam, as shown at top right in *Fig. 6*. Although, theTurkish Code considers it to be safe enough to increase the internal stress resultants of both ends of the bars associated with such a discontinuous column, the writer is in no way satisfied with such artificially invented and most probably inadequate precautions.

6. FAILURES DUE TO IRREGULARITIES IN PLAN

6.1 Torsion in L – shaped buildings

The Turkish earthquake code *(TDY 2007)* does not allow any projection in plan to be greater than 20 percent of the larger plan dimension of the building layout. Similarly, no holes or discontinuous slabs may exist greater than 30 per cent of the gross floor area. For buildings with L, T, or H shape plans, there should be proper construction joints *(expansion joints)* such that every single building part should possess a definite symmetrical rectangular shape in plan, as shown in *Fig. 7*. It is a fact that the *L* – shaped buildings are extensively damaged due to torsion during the 19.9.1985 Mexico City earthquake, of M = 8.1.

6.2 Torsion due to irregular distribution of rigidities

Extensive torsional action may also take place in a building, if there are concentrations of rigidities on one particular side of the plan, as illustrated in *Fig. 8*. The Banco Central de Nicaragua *(the building on the left hand side in Fig. 9)* for example, collapsed totally as a result of torsional failure, during the 23.12.1972 Managua, Nicaragua earthquake of ***M = 6.2***. This was because, all of the elevator and stair shafts were concentrated only on one side of the floor plan.

The high rise building on the right hand side of *Fig. 9* however, Banco de America building survived the earthquake without a single hair crack. Because, it possessed a very symmetrical and centrally located intensive core of shear walls. The degree of severity of the torsional irregularity within a particular plan is best described by the following η_b – parameter

$$\eta_b = d_{max} / d_{av} \qquad (1)$$

as described in *Article 2.3.2* of the Turkish Earthquake Code and aslo in *Fig. 8*. It is absolutely necessary that η_b should not be greater than *2*. If however it is between *1.2* and *2.0* no significant sanction is introduced any how other than increasing the accidental eccentricity.

7. SOFT STOREY IRREGULARITY

In some buildings the masonary infill walls are removed at ground floor level in order to gain commercial space for shopping centers, banks, show rooms etc. The absence of infill masonary walls, inevitably causes the ground floor level to undergo relatively larger horizontal sway, compared to upper floors during the earthquake, as shown in *Fig. 10*. Examples of buildings, heavily damaged due to soft storey irregularities, are shown in *Figs. 11 ~ 14*.

8. SHORT COLUMN IRREGULARITY

If some columns at a particular storey, are shorter in height **a)** due to the existence of masonary infill walls around them or, **b)** due to the narrow window openings at basements, as shown in *Figs. 15 ~ 16*, they are susceptible to undergo severe damages during earthquakes, to the extent of causing mostly the loss of the entire building.

9. CONCENTRATIONS OF WEIGHTS

In some buildings, a significant amount of weight (mass) may be concentrated at a particular location mostly due to architectural necessities, such as ; Heavy and bulky spandrel beams envisaged to create a monumental impression, heavy and bulky canopies with earth fills to raise green plantation, or the use of heavy facade panels, as illustrated in *Figs. 17* to *19*.

It is an earthquake engineering wonder, however, to see in *Fig. 20*, how different the two neighboring buildings performed during the same earthquake. The Hoblit show room, out of light structural steel with glass exterior did not experience even any minor damage, while the neighboring J. C. Penney shopping center collapsed totally due to torsion and heavy facade panels.

10. POUNDING OF ANY TWO ADJACENT BUILDINGS

Pounding of two adjacent buildings, without a sufficient space between them, is inevitable during a severe earthquake as shown in *Fig. 21*. The collision of two buildings, becomes relatively more vital and serious, if the levels of their floor slabs are not the same. The best and most useful advice to prevent the collision of any two neighboring buildings is to leave a minimum free space Δ, between them, calculated from the following expression :

$$\Delta = 0.015\ h \qquad (2)$$

11. DUCTILE DESIGN AND DETAILING

The element sizes and reinforcing details must conform absolutely to the ductility requirements of the relevant building design codes and specifications. A general view of a properly designed and detailed ductile beam and column reinforcement is shown in *Fig. 22*. An example for a very closely spaced column ties is also shown in *Fig. 23*. A complete treatment of ductile design of reinforced concrete elements and structures is available in references **9** and **10**. Examples of damages observed in ductile and nonductile columns are illustrated in *Figs. 24* and *25*.

12. THE 'STRONG' COLUMN CRITERION

There are numerous examples to complete catastrophic collapse of *R/C* buildings due to insufficient strength of columns. The *R/C* building designed without due care to 'strong' column criterion, is illustrated in *Fig. 26* .

13. THE JAPANESE 'MIRACLE'

If the steel columns in a building are not properly protected against fire, corrosion and earthquake, the flanges may buckle as was the case, in steel structures during the 1994 Northridge, Los Angeles earthquake *(Fig. 27)*. The Japanese applications however are much protective than those of the USA. A reinforced concrete cover of *20 cm* to *25 cm* thickness is constructed around the steel profile. Thus, the steel column is not only protected safely against fire and corrosion, but it gains a very high level of rigidity against earthquake forces. The increase in cost is less than two percent as shown in *Fig. 28*.

14. CONCLUSIONS

The twelve distinct 'golden' rules have been introduced for designing relatively safe and ductile *R/C* structures. Various illustrations are supplied not only for these ductile design examples but also for buildings damaged due to lack of these 'golden' rules.

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Figure 1. - 27.03.1964 Alaska ***(M=8.6)****, Turnagain Heights slide, Anchorage,*

Figure 2. – Liquefaction of quay walls at Rokko Island, Kobe, 17.01.1995, Japan ***(M=7.4)***

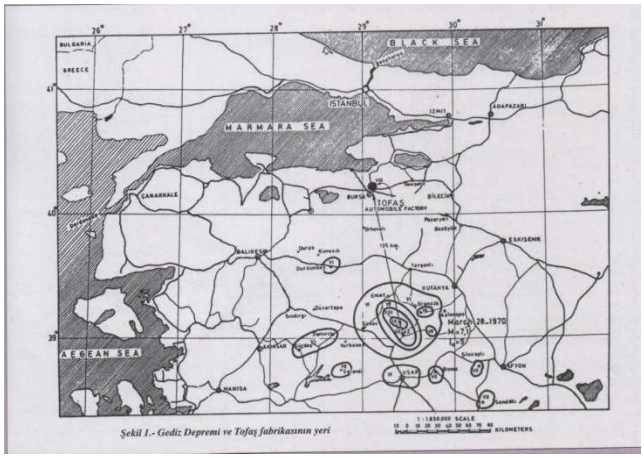

Figure 3. – 28.03.1970, ***(M=7.1)***, Gediz Earthquake and soil amplification at Tofas automobile factory.

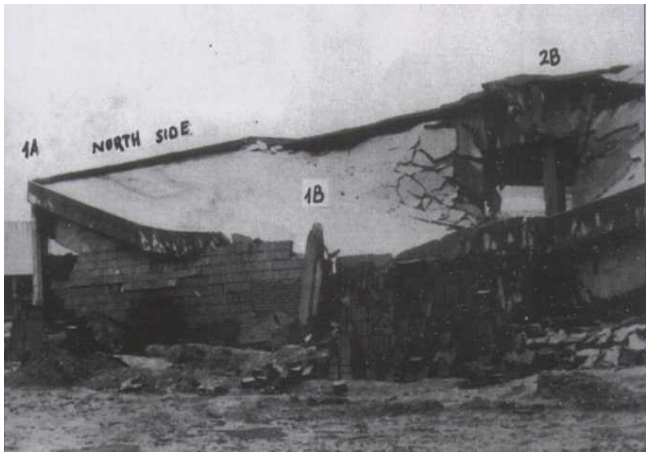

Figure 4. – Tofaş Automobile factory Paint Workshop at Bursa, 145 km north of epicenter.

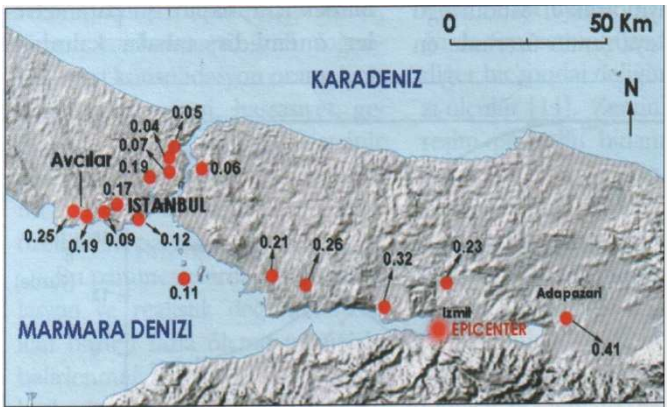

Figure 5. – 17.8.1999 Kocaeli ***(M = 7.4)***
(Accelerations reached to 0.25 g at Avcılar, 150 km away from the epicentre)

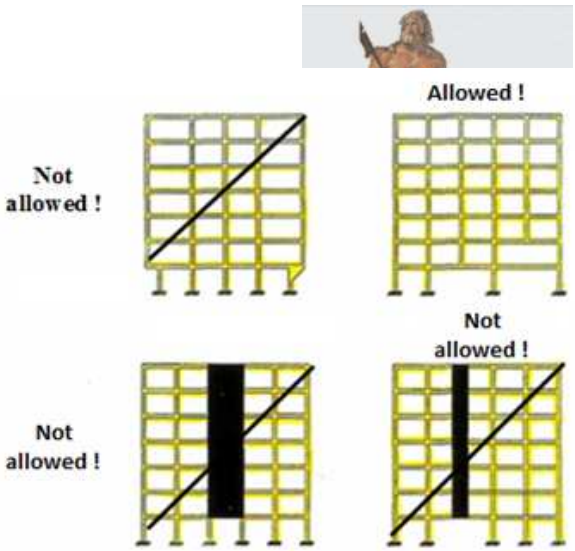

Figure 6. – Discontinued columns and shear walls ***(M)***.

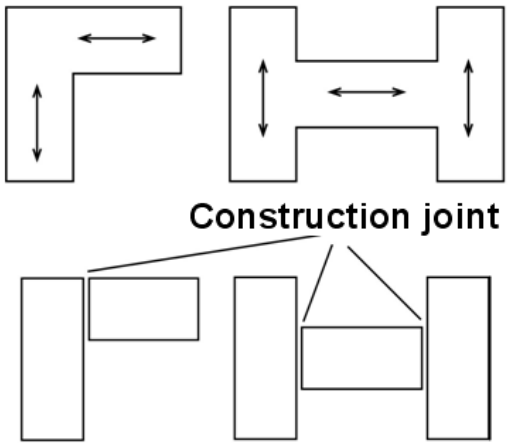

Figure 7. – L and H – Shaped Buildings

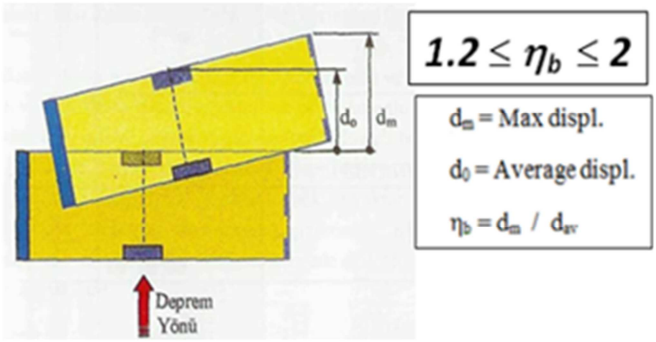

Figure 8. – Torsional irregularities η_b

Figure 9. – Banco Central de Nicaragua and Banco de America
(23 .12.1972, Managua, Nicaragua, ***M=6.2****)*

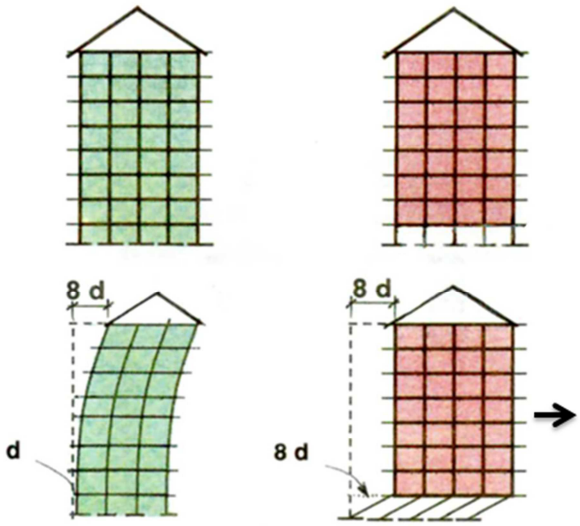

Figure 10. – Devolopment of Soft Storey

Figure 11. – Soft Storey damage
(Gölcük – Körfez Yukarı Mahalle, 17 Ağustos 1999 Kocaeli, ***M = 7.4*** *)*

Figure 12. – Soft Storey damage
("Medical Treatment and Care" binası 9 Şubat 1971 San Fernando, California, ***M=6.5***)

Figure 13. – Soft Storey damage
(San Francisco Marina Region, *17 Ekim 1989 Loma-Prieta, California Depremi,* ***M=7.1****)*

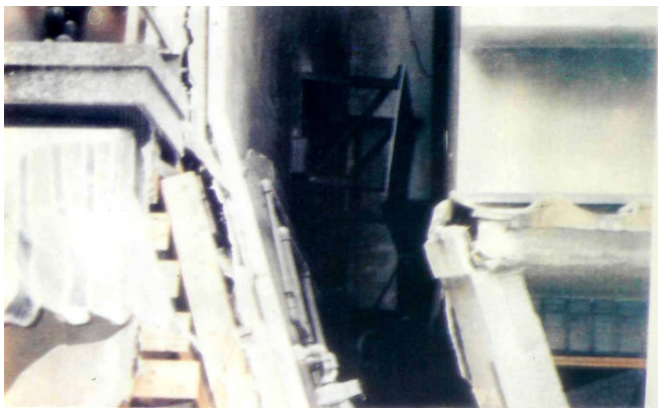

Figure 14. – Soft Storey damage
(17 .1.1995, ***M=7.2****, Kobe Earthquake)*

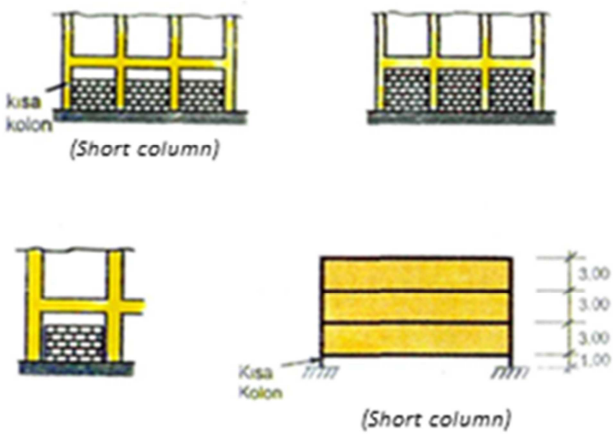

Figure 15. – Short column irregularity

Figure 16. – Short column example
(23 Aralık 1972, ***M=6.2****, Managua Nicaragua Earthquake)*

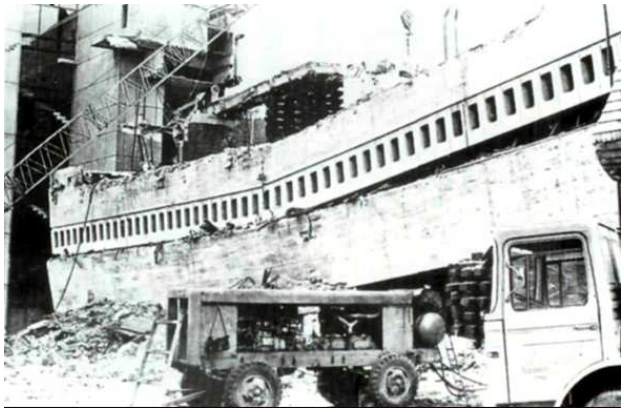

Figure 17. – The Central Computer Center Building, Heavy spandrel beams *(Bucharest, Romania, 4.3.1977, **M=7.2**)*

Figure 18. – Heavy earth filled canopies Treatment and Care, Olive View Hospital, *(San Fernando, USA, 9.2.1971, **M=6.5**)*

Figure 19. – Heavy Panels, J.C. Penney Building *(27.3.1964, **M=8.6**, Alaska Earthquake)*

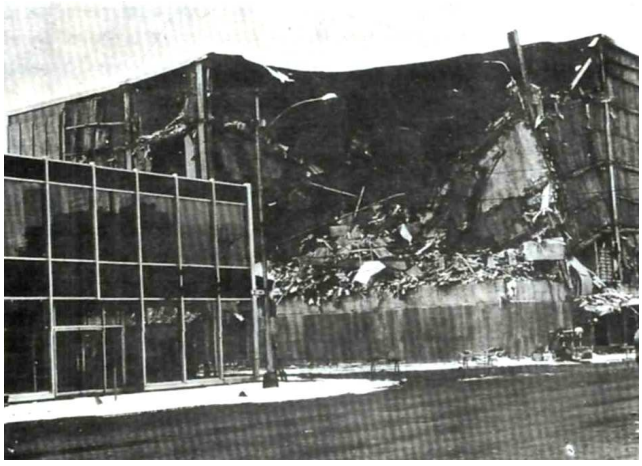

Figure 20. – Earthquake Engineering wonder *(Hoblit and J.C. Penney Building, 27.3.1964, **M=8.6**, Alaska earthquake)*

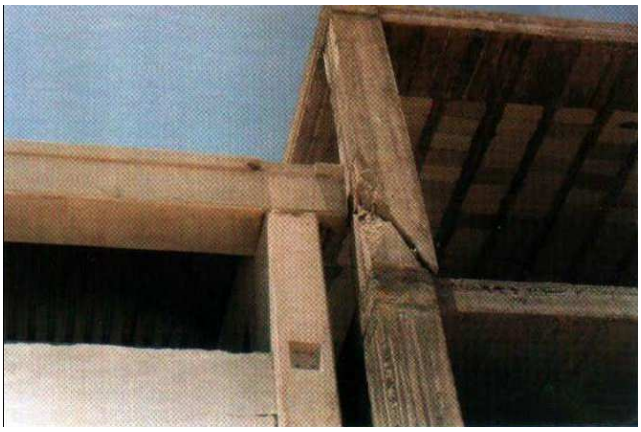

Figure 21. – Pounding of two Adjacent Buildings, Adana, 1998 *(Courtesy of Prof. F. Karadoğan, ITÜ)*

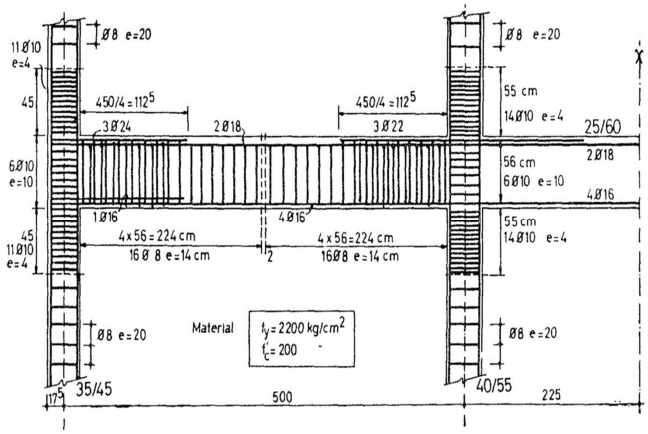

Figure 22. – Example to a ductile detailing

Figure 23. – Closely spaced ties
*(Pacific Ocean, Emeryville, San Francisco, 17.10.1989, **M=7.1**)*

Figure 24. – No confinement ties
*(17.10.1989, **M=7.1**, Loma Prieta, San Francisco)*

Figure 25. – Ductile columns of a car-park building
*(1994 Northridge LA, USA, **M=7.1**)*

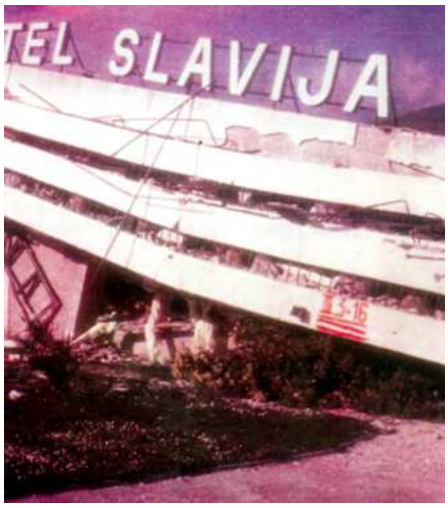

Figure 26. – Lack of 'Strong' column
*(15.4.1979 Bar-Budva, Yugoslavya, **M=7.0**)*

Figure 27. – Buckling of Flanges in the USA
*(1994 Northridge, LA, USA, **M=7.1**)*

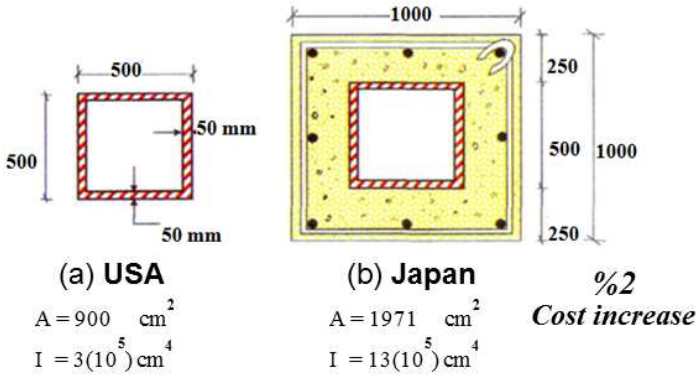

Figure 28. – The Japanes miracle
(USA and Japanese Methods of protection of columns)