EARTHQUAKE RESISTANT PRESTRESSED CONCRETE STRUCTURES

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SUMMARY

The performance of prestressed concrete structures under seismic action is not very well known. Although there are some researchers who believe in the satisfactory behavior of prestressed concrete structures under earthquake loading, there are many others who do not agree that prestressed concrete is an entirely satisfactory material for use in ductile frames. In this paper, present state of knowledge is reviewed and recommendations are made to improve the performance of prestressed concrete structures to be built is seismic areas. The recommendations made are believed to be somewhat conservative and therefore should be revised and improved when adequate data becomes available in the future.

1. INTRODUCTION

All over the world prestress concrete has been widely used in structures which are expected to carry mainly gravity and wind loads. However, prestressed concrete is not very commonly used in structures which are built in highly seismic regions. Today there are considerable differences in opinion about the satisfactory behavior of prestressed concrete structures under severe earthquake loading. The caution in the use of prestressed concrete structures in seismic regions and differences in opinion are mainly due to the lack of adequate experimental research and performance data. The limited amount of experimental data indicate that the capacity of prestressed concrete members to absorb and dissipate energy is lower as compared to conventional reinforced concrete. Also studies reveal that a prestressed concrete structure will have a maximum displacement approximately 1.2 to 1.4 times that of a conventional reinforced concrete frame having the same strength, initial stiffness and damping.

The differences in opinion on the use of prestressed concrete structures in seismic regions have been reflected in the design codes. While in some countries a very conservative approach is chosen and the use of prestressed concrete structures in highly seismic regions is almost prohibited, in other countries a more flexible approach is followed and prestressed concrete structures are permitted with certain precautions to be taken.

In Turkey the use of prestressed concrete structures in seismic areas has widespread in the recent years. Since no special precautions are mentioned in the Turkish Seismic Code, these structures are being designed and constructed like the ones built in Europe in non-seismic regions.

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This study is an attempt to provide rules and principles for the designer to design prestressed concrete structures which will behave satisfactorily under seismic action. It should be mentioned that the recommendations are made in the light of a limited number of data. As a result of this they may be somewhat conservative and therefore should be revised and improved when adequate data is available in the future.

2. BASIC REQUIREMENTS FOR SEISMIC RESISTANT STRUCTURES

2.1 General

It is generally accepted that a structure should be designed and detailed in such away that structural damage causing significant reduction in the serviceability should be prevented in moderate earthquakes and that collapse or serious damage should be avoided in severe earthquakes. As a result of this philosophy considerable amount of post-elastic deformation is expected during severe earthquakes.

Under major earthquakes a structure should have sufficient strength capacity and should be capable of developing large post-elastic deformations without exceeding the limits specified. The structure then should be able to absorb and dissipate energy in accordance with the design principles of the code without showing a brittle type of failure. This ability is called "ductility". Most of the design codes specify that the members and structures should be so designed and detailed that the required ductility and energy dissipation requirements are fully satisfied. These two major requirements, are discussed in the following paragraphs.

2.2 Ductility

The term ductility should not be used without making reference to the type of ductility given below.

a. Material ductility,
b. Section ductility,
c. Curvature ductility at the plastic hinge,
d. Member ductility.

These four different ductility concepts are illustrated in Figure 1. In general the ductility demand for one is different from the other. For example in a structure the curvature ductility demand at the plastic hinge is greater than the displacement ductility (member ductility).

In a structural system all four types of ductility demands should be satisfied.

2.3 Energy Dissipation

For structures to be built in high seismic regions the capacity of the member to absorb and dissipate energy is as important as the strength requirements.

Although ductility is defined as a ratio of the deformations (strain, displacement or curvature), energy absorbing capacity is the product of deformations and the forces which cause these deformations. In other words, it is the work done while the deformation under consideration is accomplished.

A member having adequate ductility may not have the desired energy absorption capacity. This is illistrated in Figure 2 by comparing the responses of a conventional and prestressed concrete member. Although the two members have comparable ductility, energy absorbed are quite different.

3. SPECIAL REQUIREMENTS FOR PRESTRESSED CONCRETE STRUCTURES IN SEISMIC AREAS

3.1 General

At the present time there are at least some doubts about the performance of prestressed concrete structures under seismic actions. Main reasons for this are summarized below.

- There is a limited number of experimental data on the behavior of prestressed concrete members and structures under seismic loads.
- Performance records are not available for fully prestressed structures subjected to real severe earthquakes.
- Some of the major Seismic Codes do not encourage the use of prestressed concrete structures in high seismic zones (like SEAOC).
- Without conventional steel, energy dissipation occurs only as a result of crushing of concrete and not as a result of steel yielding.
- Research work reported by several engineers indicate that the displacement of the fully prestressed concrete frame can be 1.2-1.4 times that of a reinforced concrete frame having the same strength, initial stiffness and damping.

Although the statements made above are enough to make the design engineer cautious about the use prestressed concrete in structures to be built in seismic regions, the authors believe that such structures can be designed and built by taking certain precautions.

Two different approaches which can be employed are given below.

3.2 Prestressed Concrete Structures with Non-prestressed Lateral Load Resisting Members

The performance of a prestressed concrete structure in seismic region can be made satisfactory if non-prestressed members are introduced to resist the total lateral load due to the earthquake. Although this is a safe approach it might not be a desirable solution for the designer. Also the designer might find this approach too conservative. In such cases he should adopt the second approach which intends to produce a "ductile moholithic structure".

3.3 Ductile Monolithic Structures

It is possible to increase the ductility and capacity to absorb and dissipate energy of prestressed concrete structures by taking certain precautions. These can be summarized as (a) partial prestressing and (b) magnification of the lateral loads.

3.3.1. Partial prestressing

Experimental research indicate that the ductility and the capacity to absorb and dissipate energy can be greatly improved by placing conventional reinforcing steel in the cross-section in addition to prestressing steel. For partial prestressing one of the following alternatives can be employed.

- Prestressing steel area obtained for the fully prestressed case is retained but the level of prestressing force is reduced. The reduced capacity is compensated by adding conventional reinforcing steel.
- Area of the prestressing steel is reduced and the ultimate capacity is reserved by adding conventional reinforcing steel. It can be recommended that about 15 to 20 precent of the ultimate capacity should be provided by the additional reinforcing bars.

However the designer should be careful not to produce an overreinforced section by placing additional conventional steel. It should also be noted that the curvature ductility of a prestressed concrete member decreases with increasing content of prestressing steel. Therefore the mechanical percentage of prestressing steel should be limited.

$$\rho_{ps} \leq 0.2 \frac{f_{ps}}{f_{ck}}$$

ρ_{ps} = Percentage of prestressing steel, $\frac{A_{sp}}{bd}$

f_{ps} = Stress in prestressing steel at the flexural strength

f_{ck} = Characteristic compressive strength of concrete

3.3.2. Magnification of the lateral loads

As was mentioned previously the displacement of a fully prestressed frame is greater than that of a conventional reinforced concrete frame. For this reason a magnification factor will be essential for the drift requirements. At the present time, in the light of limited research data, a magnification factor of 1.2 seems to be reasonable. Such magnification factors are included in the design codes of New Zealand and Canada.

4. CONCLUSIONS

Limited experimental data is available on the seismic behavior of prestressed concrete members and structures. Also performance records of fully prestressed concrete structures subjected to real severe earthquakes are lacking. Therefore a conservative approach is recommended for the design of such structures to be built in high seismic regions. The designer should choose one of the following two alternatives.

a. Nonprestressed members can be introduced to resist the total lateral force.
b. Lateral loads can be magnified and partial prestressing can be introduced.

5. REFERENCES

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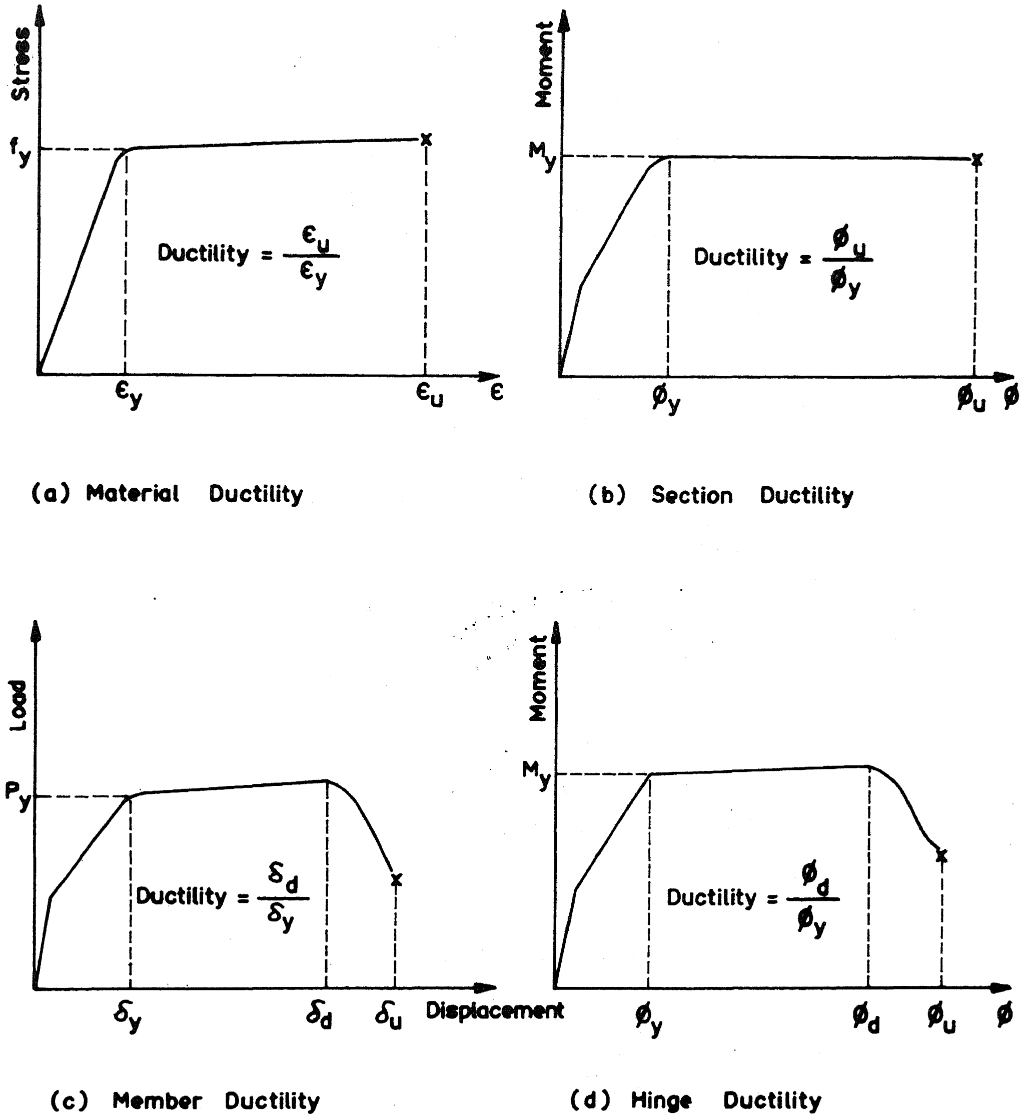
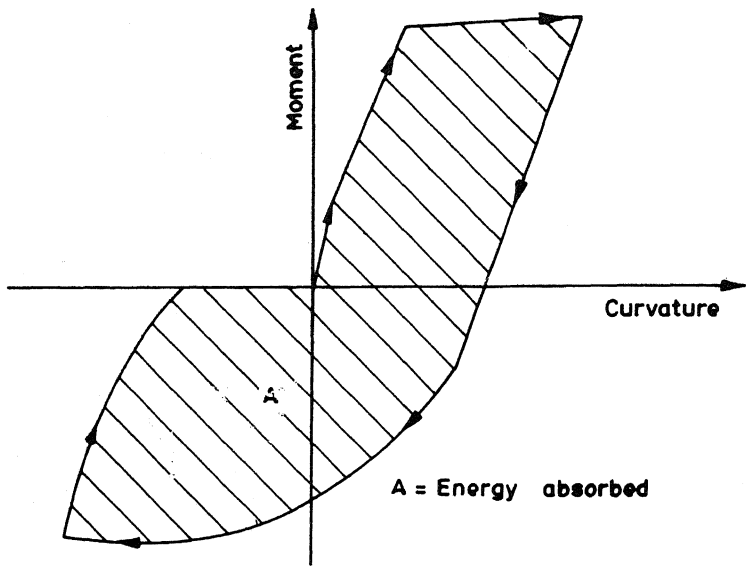
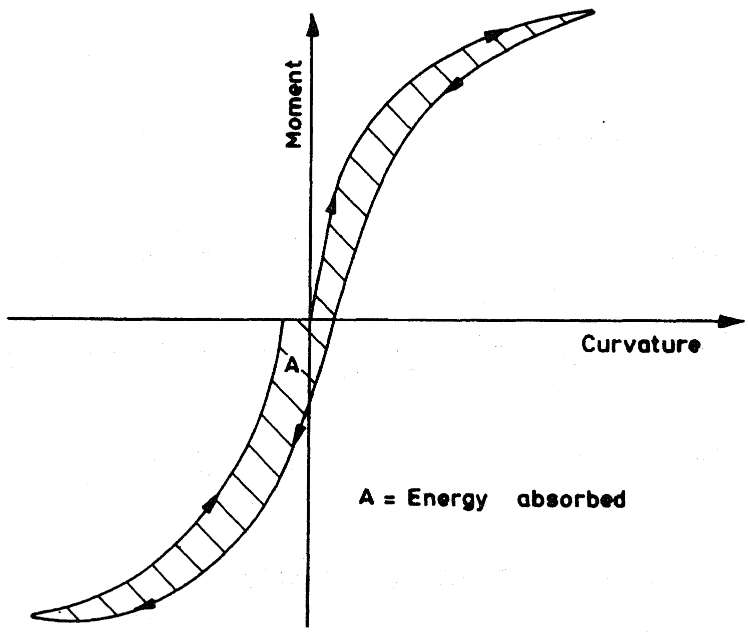


FIGURE 1 TYPES OF DUCTILITY



(a) Reinforced concrete members



(b) Prestressed concrete members

FIGURE 2 ABSORBED ENERGY