# TESTING OF PLAIN AND FIBER CONCRETE CANTILEVER BEAMS UNDER VARIOUS DYNAMIC TESTING CONDITIONS

# SADE VE FİBERLİ BETON KİRİŞLERDE DEĞİŞİK DİNAMİK KOŞULLARDA DENEYLER

Lidija Krstevska*, Ljubomir Tashkov**, Dimitar Jurukovski**

## ABSTRACT

Presented in this paper are the results obtained by testing of four different types of plain and fiber concrete cantilever beams under quasistatic loading conditions, as well as under dynamic harmonic, impulse and earthquake excitation. The objective was to determine the differences caused by the presence of steel fibers in the concrete reflected in the strength and deformability characteristics, energy absorption capacity, damping, failure mechanism and others. The tests have proved that the effect of the fibers is considerable in the case of non-reinforced concrete, while in the case of reinforced concrete no pronounced difference in the dynamic behaviour has been observed.

## INTRODUCTION

The concrete is a building material widely applied in structures of different types and usage, considering its high strength in compression. The need of concrete as a building material but with improved deformability characteristics is especially actual in seismic prone areas, as well as for the structures exposed to impulse and abrupt loadings. This need led to development of fiber concrete and a grate number of investigations in the institutions all over the world have pointed out its improved mechanical and deformability characteristics.

Most of these investigations are dealing with the behaviour of fiber concrete under static and cyclic loading conditions, while data about the behaviour of this material under dynamic conditions are limited. So, the main objective of performed investigations in the Institute of

* Assist.Prof., Institute of Earthquake Engineering and Engineering Seismology, Skopje, Republic of Macedonia

** Prof.Dr., Institute of Earthquake Engineering and Engineering Seismology, Skopje, Republic of Macedonia

Earthquake Engineering and Engineering Seismology, Skopje, Macedonia, was to study the differences in the behaviour of fiber concrete with selected type of steel fibers, in respect to the plain concrete, when subjected to dynamic loading conditions. Four types of cantilever beams were tested applying three types of dynamic excitation: harmonic, impulsive and earthquake excitation. The obtained results are presented herein.

## EXPERIMENTAL PROGRAMME

### Description of Tested Elements

Mechanical and strength characteristics of plain and fiber concrete were defined first. The same concrete mixture was used in both cases and the quantities of materials used for concrete matrix are presented in Table 1. For fiber concrete smooth steel fibers with hooks at the ends were used, 1% by volume. The fibers had an aspect ratio of 80 (length 32 mm and diameter 0.4 mm).

Table 1. Materials in the concrete

| | |
|---|---|
| Cement | 410 $kg/m^3$ |
| Aggregate 0-4mm | 736 $kg/m^3$ |
| Aggregate 4-8mm | 313 $kg/m^3$ |
| Aggregate 8-16mm | 791 $kg/m^3$ |
| water to cement ratio w/c | 0.50 |
| plasticizer | 1.2% |
| steel fibers | 80 $kg/m^3$ |

Table 2. Strength characteristics of the concrete

| concrete type | compressive strength MPa | direct tension strength MPa | strength in flexure MPa | max. shear force kN |
|---|---|---|---|---|
| plain concrete | 48 | 2.1 | 4.8 | 35 |
| fiber concrete | 52 | 3.4 | 11.1 | 46 |

The strength in compression was obtained on cubes 20x20x20cm. The specimens for defining direct tension strength and tension strength in flexure (third point loading, span 30cm), as well as shear strength, were prismatic trial specimens. Tests for defining the strength characteristics of the concrete were performed by monothonic loading - 1mm/min. Table 2 presents the obtained strengths.

For quasi-static and dynamic testing four different types of cantilever beams, having geometry shown in Fig.1, were constructed:

-beam M1 - beam of plain concrete, without classical reinforcement;

-beam M2 - beam of fiber concrete, without classical reinforcement;

-beam M3 - classically reinforced beam of plain concrete (4$\phi$16);

-beam M4 - classically reinforced beam of fiber concrete (4$\phi$16).

Dynamic testing of beams was performed in the Laboratory for Dynamic Testing in the Institute of Earthquake Engineering and Engineering Seismology in Skopje, on one componental seismic shaking table. The capacity of this electro-hydraulic system-earthquake simulator, is max. dynamic force of 100kN for model with mass of 1000kg. Dynamic system of tested beams was a single degree of freedom system, with mass of 350kg at the top of the beam (free end), having natural frequency of 5.0 Hz. The beams were instrumented with accelerometers, displacement transducers and strain gages for measuring of all parameters of interest, Fig. 2.

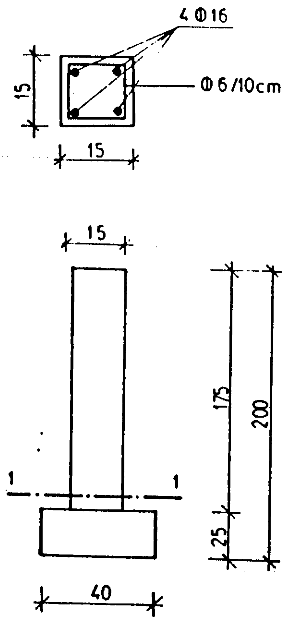


Fig.1. Beams geometry

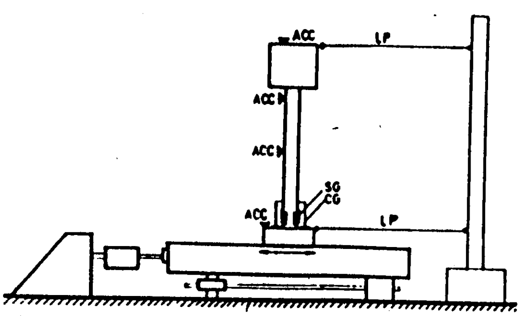


Fig.2. Beams set up for dynamic testing

**Dynamic Testing Procedure**

Quasistatic testing was performed applying an alternative force at the free end of the beam. The force was applied gradually, with repeating the cycles. To study the behaviour of the beams under dynamic excitations three different types of dynamic excitations were applied: harmonic excitation with frequency close to the natural frequency of the system, triangular impulse excitation with $\Delta t=40$ msec (Fig.3) and earthquake excitation El Centro, scaled two times in order to get the predominant frequency of excitation close to the frequency of the tested system. The time history and spectrum of the earthquake are shown in Fig.4. The dynamic force was applied in steps and testing programme was identical for the beams of plain and fiber concrete without classical reinforcement, i.e. for the beams of ordinary and fiber concrete classically reinforced. All beams have been tested up to failure. Table 3 presents the tested types of beams and corresponding annotation.

Table 3. Annotation of tested beams

| description (type) of beam | excitation | annotation |
|---|---|---|
| plain concrete,no classical reinforcement | quasistatic | M1K |
| | harmonic | M1H |
| | impulse | M1I |
| | earthquake | M1Z |
| fiber concrete, no classical reinforcement | quasistatic | M2K |
| | harmonic | M2H |
| | impulse | M2I |
| | earthquake | M2Z |
| ordinary concrete, classically reinforced | quasistatic | M3K |
| | harmonic | M3H |
| | impulse | M3I |
| | earthquake | M3Z |
| fiber concrete, classically reinforced | quasistatic | M4K |
| | harmonic | M4H |
| | impulse | M4I |
| | earthquake | M4Z |

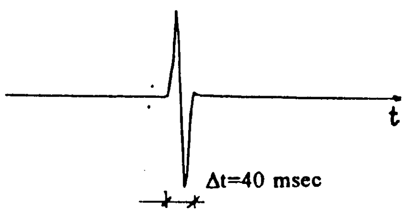


Fig.3. Applied Impulse Excitation

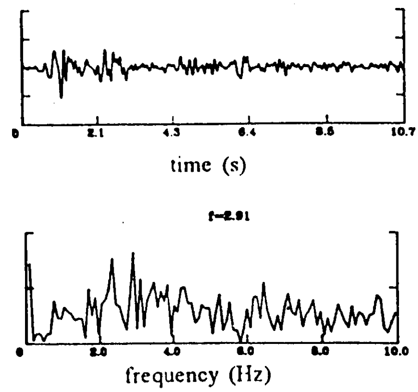


Fig.4. Time history and spectrum of applied earthquake

## EXPERIMENTAL RESULTS

### Quasistatic Testing

The relationships force-displacement at the free end of the beams are presented in Fig.5 and in Fig.6, for nonreinforced and for reinforced beams, respectively. It is obvious that practically there is not difference in the strength of the beams made of ordinary and fiber concrete. But there is an important difference in energy absorption capacity of the beam made of fiber concrete in respect to the beam made of plain concrete. The area of the hysteretic loop of the fiber concrete beam is about two times larger, as shown in Fig.7, and the reason of this is energy requirement for pulling out of the fibers from the concrete. The failure of the plan concrete beam is brittle with sudden loose of carrying capacity, while for the fiber concrete beam, even the first crack caused loose in the strength, in the next few cycles fibers are activated in the section of the crack and in further cycles they are carrying a significant value of the flexural load, about 65% of the maximum force. For classically reinforced beams such a difference is not observed.

### Dynamic Testing

Force - displacement relationships are presented in Fig.8 for harmonic and earthquake excitation for test before first crack occurrence and test when first cracks occurred. It is obvious that for the plain concrete beams first crack means failure of beam, while for the fiber concrete beams first crack occurrence is followed by mobilization of the fibers in the crack and energy absorption due to fibers pull out. In the case of fiber concrete beam integrity of the element has been kept. The most favourable behaviour was observed in the case of earthquake excitation, with gradual strength and stiffness decrease.

From the force - displacement relationships presented in Fig.9 for beams with classical reinforcement it could be concluded that there is not evident difference between the beams made of plain concrete and the beams made of fiber concrete.

The damping coefficients for the beams obtained by logarithmic decrement method, using the acceleration time histories measured at the free end, Fig.10, showed that for the beam of fiber concrete without classical reinforcement the increasing in damping, due to the presence of steel fibers, is about 20%, while in the case of classicaly reinforced beams this difference is less than 10%.

The efficiency of steel fibers in controlling deflection of the classical reinforced beams was observed for all types of dynamic excitations applied during the experimental testing of beams. After first crack occurrence, for greater intensities of motion greater reduction in top displacement was observed.

Considering the failure mechanism of the beams for given excitation, as shown in Fig.11, it could be said that for plain concrete beams without classical reinforcement there was only one critical section; for fiber concrete beams without classical reinforcement there was additional crumbling of concrete around the critical crack section because of the fiber presence in the concrete. For classical reinforced beams most damaged was the section at the fixed end with a lot of parallel cracks along the height, which is characteristic for elements loaded in flexure, but in the case of fiber concrete beams two 'main' cracks near the fixed end occurred, at a small distance from each other. It could be concluded that the pressence of fibers increased the length of plastic hinge in these beams and that they have a greater rotation capacity, i.e. greather ductility comparing to the beams of plain concrete.

## CONCLUSIONS

Based on the results of experimental investigations of behaviour of plain and fiber concrete cantilever beams under various dynamic excitations next conclusions could be drawn:
-for addopted type and amount of fibers all mechanical characteristics of concrete were improved;

-dynamic testing showed that the main efficiency of fibers is in improvement of damping and deformability characteristics for all dynamic excitations apllied: harmonic, impulse and particularly for earthquake type;

-the efficiency of fibers, i.e capability for deformation control appears after first crack occurrence and it is proportional to the strain rate of loading.

## REFERENCES

1. Krstevska, L., Tashkov, Lj. (1990) "Comparison of Behaviour of Cantilever Beams Made of Plain and Fiber Concrete Tested under Resonance Conditions", V$^{th}$ Kongres of SDSGJ, Bled.

2. Krstevska, L. (1992) "Analysis of the Behavior of Fiber Concrete under Various Dynamic Conditions Based on the Results of Experimental Testing", Master Thesis, Skopje.

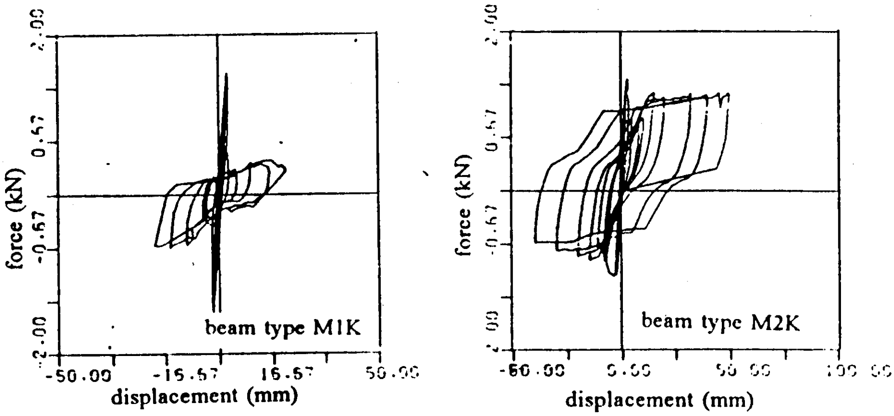


Fig.5. Force-displacement relationships for beams type M1K and M2K (quasistatic test)

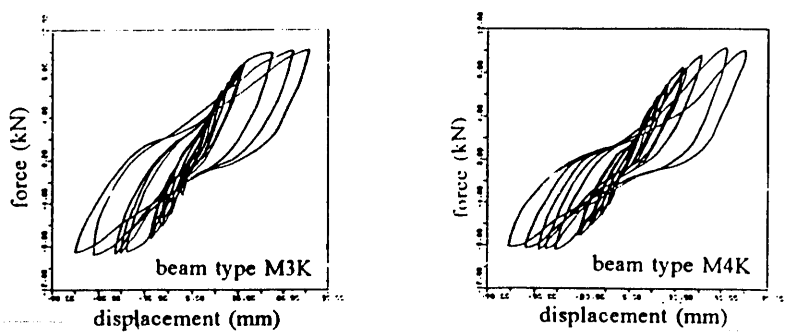


Fig.6. Force-displacement relationships for beams type M3K and M4K (quasistatic test)

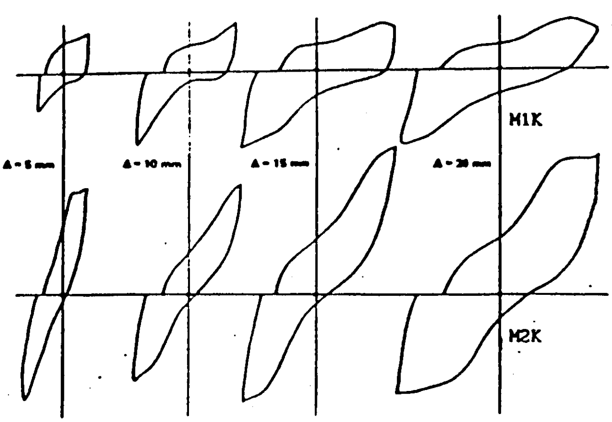


Fig.7. Energy dissipation in few cycles for beams type M1K and M2K (quasistatic test)

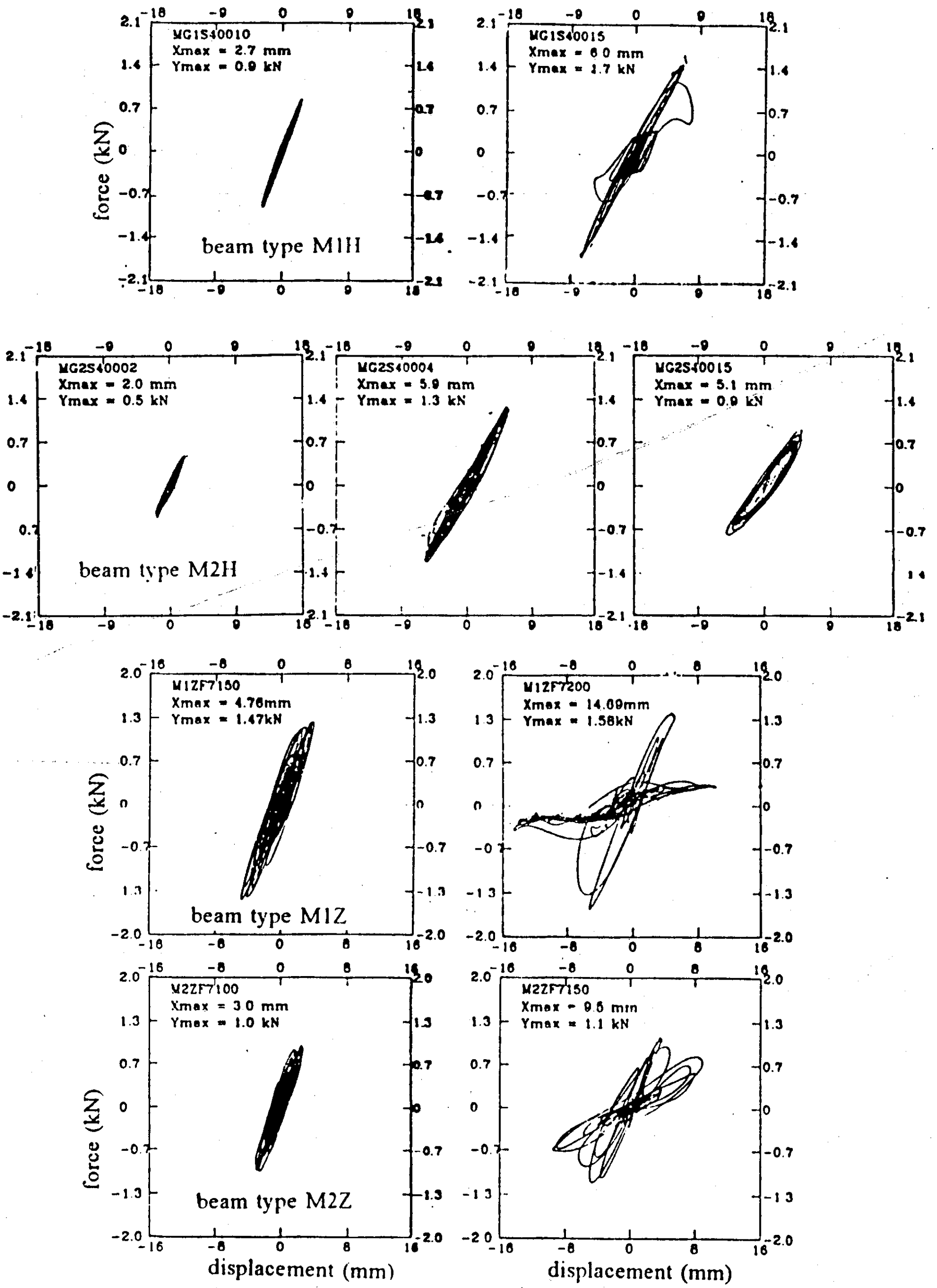


Fig.8. Force-displacement relationships for beams without classical reinforcement

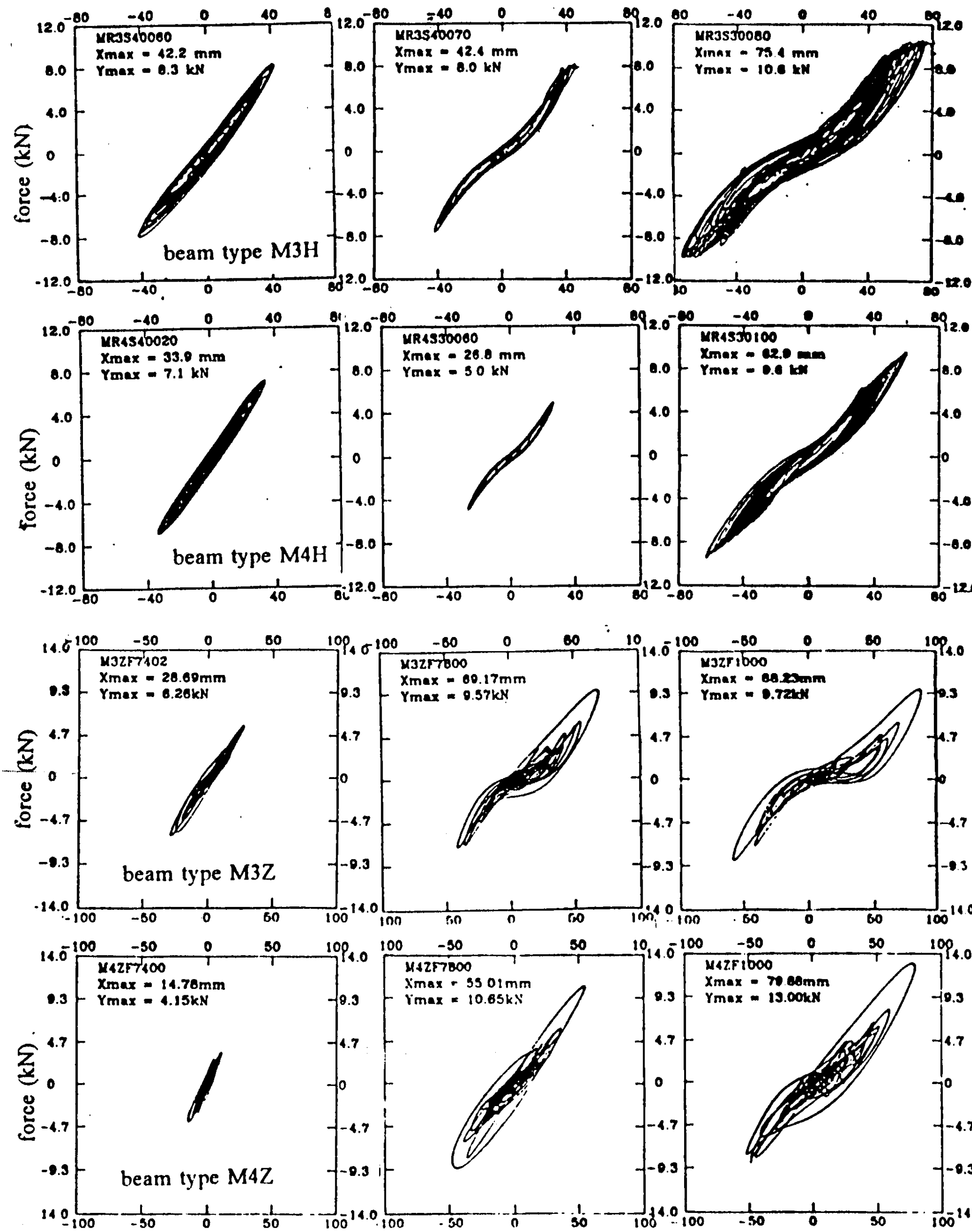


Fig.9. Force-displacement relationships for beams with classical reinforcement

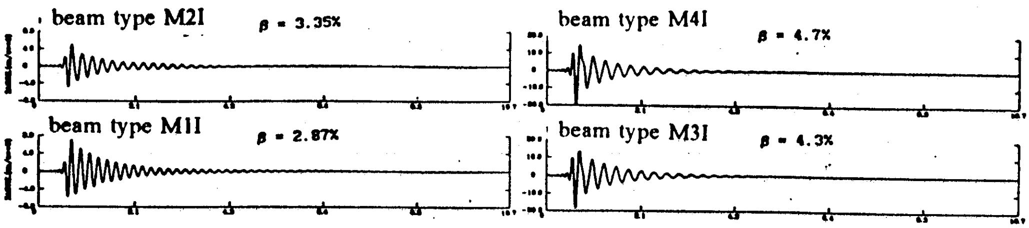


Fig.10. Damping coefficients of the beams obtained by logarithmic decrement method

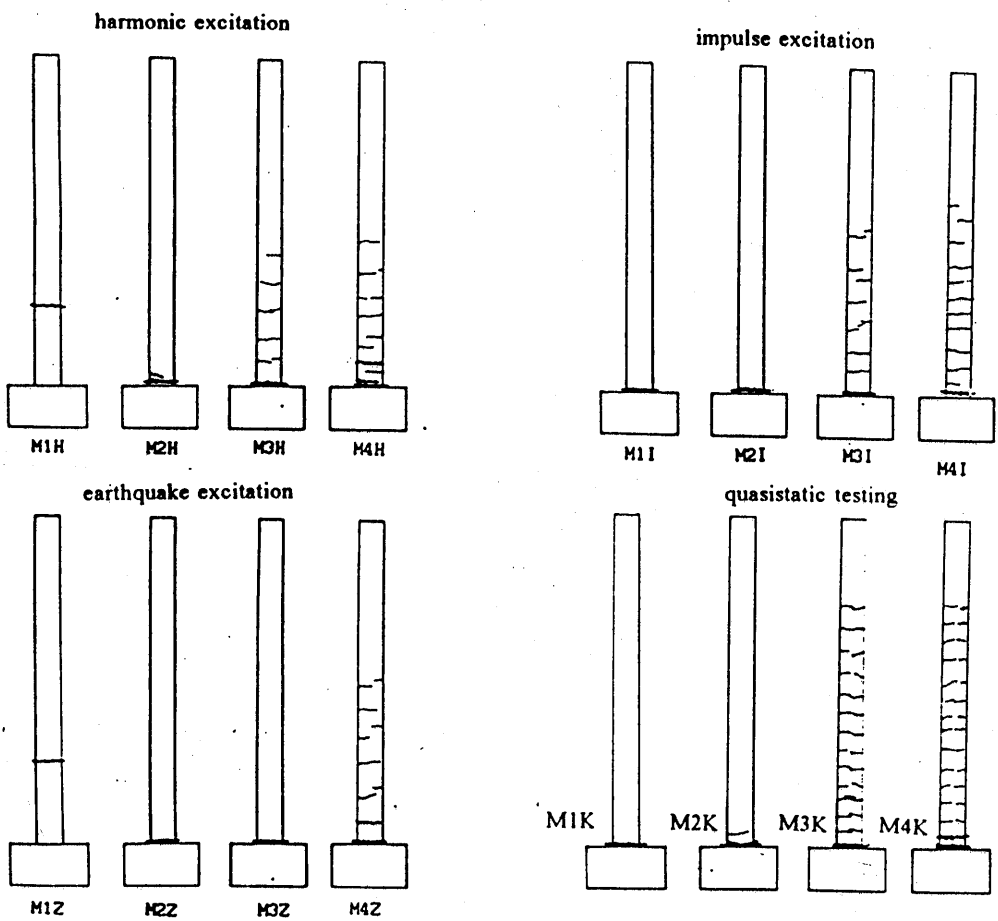


Fig.11. Failure mechanism of the beams

# SADE VE FİBERLİ BETON KİRİŞLERDE DEĞİŞİK DİNAMİK KOŞULLARDA DENEYLER

**Lidija KRSTEVSKA - Ljubomir TASHKOV - Dimitar JURUKOVSKI**

Bu çalışmada, yarıstatik, harmonik, deprem ve darbe tipi etkiler altındaki, alışılagelmiş beton ve fiberli betondan imal edilmiş dört ayrı türdeki konsol kirişin deney sonuçları sunulmaktadır. Amaç; mukavemet, şekil değiştirme özellikleri, enerji yutma kapasitesi, sönüm ve göçme mekanizması gibi karakteristik büyüklüklere çelik fiberin etkisini görmektir. Deney sonuçları fiber kullanmanın, donatısız betonda önemli etkileri olduğunu ancak donatılı betonun dinamik davranışında önemli farklar yapmadığını ortaya koymaktır.