NONSTATIONARY STRUCTURAL SYSTEMS

WITH INCREASING STIFFNESS

A. Spasov[I], V. Simovski[II]

SUMMARY

The paper deals with and discuss the problem of nonstationary systems. A nonstationary bilinear system is treated as a classical frame structure with diagonal members. These diagonals can either be cables or specially constructed diagonal braces which are activated after certain displacement level is reached. Such a structure represents a bilinear system with increasing stiffness, having variable dynamic properties which result in a nonstationary character of the system.

Taking into account the fact that the stationary system is adaptable to external excitations, the analysis which was carried out has shown that the response of such a system is usually lower than the response of a corresponding linear system.

Also, the problem of nonstationary systems with degrading stiffness has been considered in this paper.

1. INTRODUCTION

In order to reduce the earthquake effects, nonstationary systems should be designed. Due to their variable dynamic characteristics they do not fell in resonance during vibrations. Also, their response is smaller than the response of the corresponding linear systems.

The nonstationary systems can have connections which could either be included or excluded from the vibration.

The systems in which the connections are excluded are subject of stiffness decreasing due to failure in connections. They have the advantage of nonstationary systems but also the disadvantages resulted from the decreased stiffness and increased deformations. These disadvantages are similar to those involved in classically designed structures. Namely, while they are in plastic range, the classically designed structures are of nonstationary character. The systems having degrading stiffness can avoid these disadvantages if connections can be excluded through a mechanism which will provide nonstationary-elastic behaviour.

It is known that in earthquakes of short duration, high frequency components are prevailing in the epicentral zone. Structures having excluding

I Professor, Faculty of Civil Engineering, University "Kiril and Metodij" Skopje, Yugoslavia

II Assistant Professor, Faculty of Civil Engineering, University "Kiril and Metodij", Skopje, Yugoslavia

connections have large initial stiffness and therefore they are sensitive to this type of earthquakes. In such case, preference should be given to nonstationary systems having increasing stiffness.

Therefore, systems of incresing and degrading stiffness should be introduced. These systems have bilinear P-Δ relationship and a possibility for reversible process.

A short duration earthquake is considered as specially interesting excitation for this type of structures. For the purpose of analysis, several types of actual earthquakes have been adopted (Parkfield, June 27, 1966, ST-2 ; Ancona, June 14, 1972, and one synthesized earthquake- Skopje"N").

2. BILINEAR CONCEPT OF NONSTATIONARY SYSTEMS

This concept is similar to the concept for design of steel structures with diagonally braced frames. However, the difference is in the fact that the diagonals of the proposed system allow certain free storey displacement. The free storey displacement is limited depending upon the adopted design concept (Fig.1). After certain displacement level is reached, the diagonals are activated. Thus, the system gets both an increased stiffness and a nonstationary character and performs as bilinear system with increasing stiffness. Furthermore, the diagonals can be as designed, so that they can be excluded when certain level of storey displacement which corresponds to a limited force, is achieved. In this case, the system works as a bilinear nonstationary system with degrading stiffness (see inserts of figures 3, 4 and 5). Mathematical models of the two systems are shown in Fig.2a and Fig.2b.

By varying the section and the structure of the diagonal, the stiffness of the system can also vary. It is adopted in this paper that the stiffness in the second line of the P-Δ relationship is 1.5, 2.0 and 3.0 from the initial stiffness. For illustration purposes, a system of degrading stiffness has been presented, for which the second line of the P-Δ relationship is 0.5 and 0.75 of the initial stiffness. This variation was adopted in order to define its influence upon the response of the structure.Whether the relation between the two stiffness lines will be adopted depends in practice upon many factors. However, this problem is not a subject of investigation in this paper.

The structural system proposed for earthquake resistant design has the following advantages:

(1) The response of a nonstationary bilinear system is lower compared to the response of a corresponding linear system. This conclusion applies to many systems of the spectrum. The accuracy of the response of a system from the spectrum can be defined by varying the relation between the two lines of the P-Δ realtionship and varying the limiting storey displacement, that is through the limiting force of the diagonals.

(2) Because the deflection of the system is lower, the P-Δ effect due to the vertical load is lower. The stiffness is increased and consequently the safety of the system against collapse is increased.

(3) The additional connections, besides the nonstationarity, they add to the load capacity of the system. It is important to note , that an increase of the load carrying capacity is achieved by axial forces (tension, of the diagonals). Such system could have a good behaviour in the plastic range, which should be proved by further investigations.

(4) The system is selective at the beginning while subjected to shallow earthquakes in the epicentral zone. It is suitable for high-rise buildings when subjected to long-distance earthquakes.

(5) The nón-stationarity of the system could be varied easily. Applying the knowledge of future investigations about the characteristics of the expected earthquakes and the behaviour of the structures, by a simple change of the diagonal properties, another better system can easily be obtained.

(6) On certain location having specific seismic characteristics, applying this concept, a building could be built which as a linear system is practically very difficult to be achieved.

(7) In connection with the local seismic characteristics of the location the nonstationarity of the system can be designed so that an optimum system is obtained.

(8) Structures well designed by this concept can simply be repaired after being damaged during strong earthquakes, by replacing the diagonals.

These are some of the advantages of the proposed system over the classically designed systems. The seismic forces for which these systems should be designed are about the same as those of the linear systems with the same initial stiffness. However, the proposed system would carry the seismic forces to a great extent by the axial forces rather than by bending. Therefore, this system should be cheaper than the classically designed systems.

One disadvantage of the proposed system is that of the diagonally braced steel buildings. The diagonals represent a limitation to the architectural design.

3. RESULTS OF THE ANALYSIS

For investigation of the behaviour of a bilinear system (Fig.2) two actual earthquakes of short duration were selected, namely, Parkfield 1966, ST.2 and Ancona of June 14, 1972, and one synthesized earthquake, Skopje "N".

The earthquakes of Parkfield 1966 ST.2 and Ancona, June 14, 1972 are well known. The earthquake Skopje "N", represents an artificially generated earthquake of duration 4.50 sec and a maximum ground acceleration of 50% g. The Skopje "N" earthquake was obtained applying the Jennings,Housner, Tsai method.

One degree of freedom system was analysed using the following natural periods:0.2, 0.5, 1.0, 1.6, 2.5 sec.

The nonstationarity of the system was varied by changing the displacement at the point of stiffness change, and the ratio of the two stiffnesses of the system. The point of stiffness change was connected to the maximum displacement response of the linear system.

In Figs.4 and 5 a case when $\Delta = \frac{\Delta max}{8}$ is presented. Fig.3 shows the cases when $\Delta = \frac{\Delta max}{8}$ and $\Delta = \frac{\Delta max}{4}$ The ratio adopted for the two stiffnesses was $K_1 = 1.5K$, $K_1 = 2.0K$, $K_1 = 3.0K$, $K_1 = 0.5K$, $K_1 = 0.75K$.

Some of the results obtained by this analysis are shown in Figs.3, 4 and 5, at the end of this paper. For the purpose of comparison, results obtained by analysis of a corresponding linear system (Δ max) are also given. The periods of the bilinear system are initial ones. Viscous damping of 5% critical was adopted.

For the selected relations of $k \div k_1$ in the P-Δ relationship, the most favourable responses for different periods of the system and different earthquakes were obtained.

In the case of the Parkfield earthquake (Fig.3), as one can see, except for the period of 2.5 sec the bilinear system has lower response than the response of the linear system. By increasing the bilinearity, i.e. the stiffness k_1, the response decreases (Fig.3). That decrease goes down to about 3 times (for T= 0.2 sec.). The response also decreases by decreasing the displacement of the starting point of the incresed stiffness Δ (starting point of action of the diagonals). In both cases, the system works more and longer as bilinear, and consequently the response is decreased. High decrease of the response is noticed at periods of 0.2, 0.5 and 1.6 sec.

Large effect of the bilinear system is present at the period of 1.6 sec. The period of about 1.6 sec is approximately equal to the period of ground displacement of the earthquake. As shown in the previous work (Ref.1) a building with similar period is practically impossible to be designed as resistant to such an earthquake. However, if such a structure is built as a bilinear one, the response of the structure would decrease about 2.3 times and the structure could be earthquake resistant.

The response of the linear and bilinear system during vibration, for characteristic periods is shown in Figs. 6, 7 and 8. The proposed bilinear system was analysed for Parkfield 1966 earthquake ST.2, Ancona earthquake of June 14, 1972 and the artificial earthquake Skopje-"N". All these earthquakes are of short duration similar to the Skopje earthquake of 1963.

4. CONCLUSIONS

The proposed nonstationary bilinear system gives a possibility to look for more favourable response compared to the response of the corresponding linear system .

The favourable response should be a result of variation of the non-stationary elements in the system, of the relation between the two lines in the P-Δ relationship, and the starting point when diagonals are activated.

In order to come to general conclusions concerning the behaviour of such a system, the same system should be analysed for larger number of different earthquakes.

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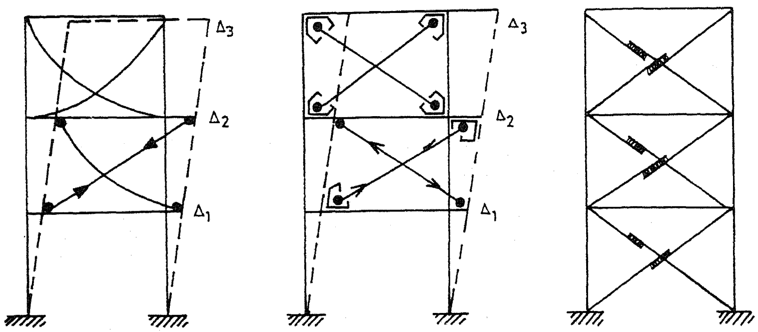
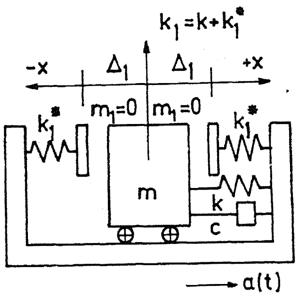
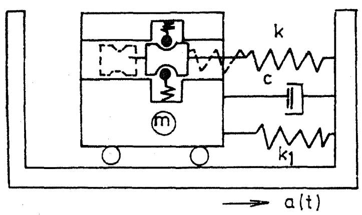


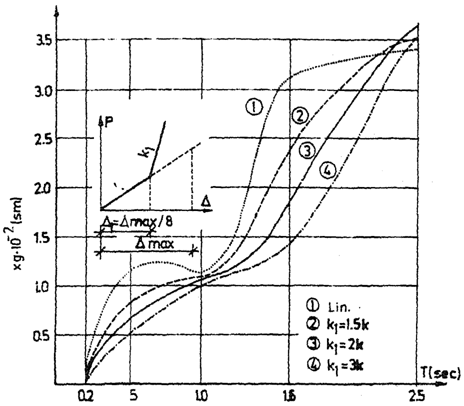
"Fig.1" Systems with including and excluding connections



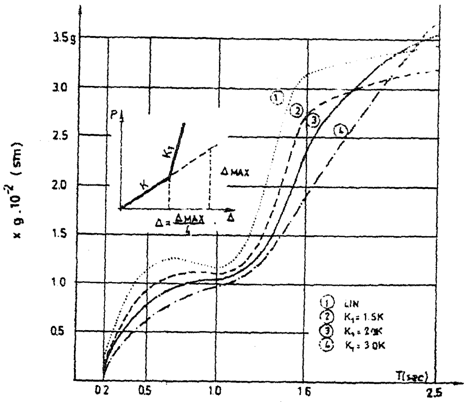
"Fig.2a"



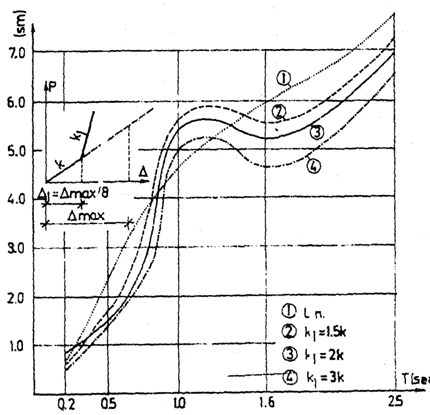
"Fig.2b"



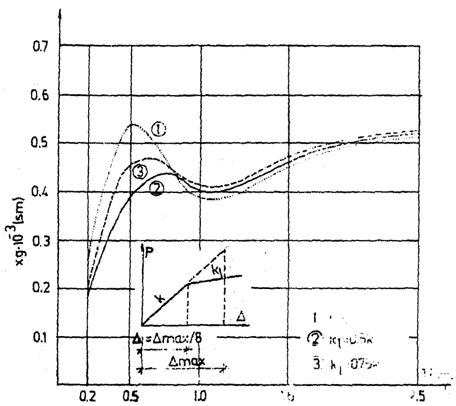
"Fig.3a" Parkfield earthquake 1966, ST.2
Response to displacement



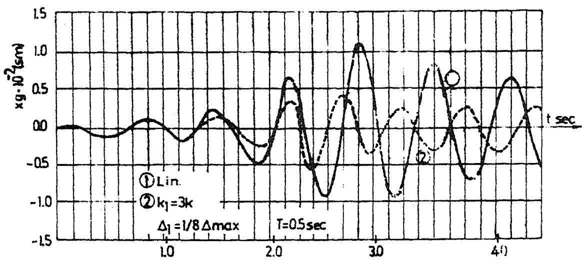
"Fig.3b" Parkfield earthquake
Response to displacement



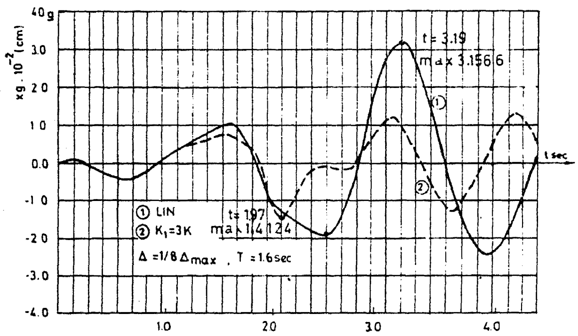
"Fig.4" Skopje"N" earthquake- simulated
Response to displacement



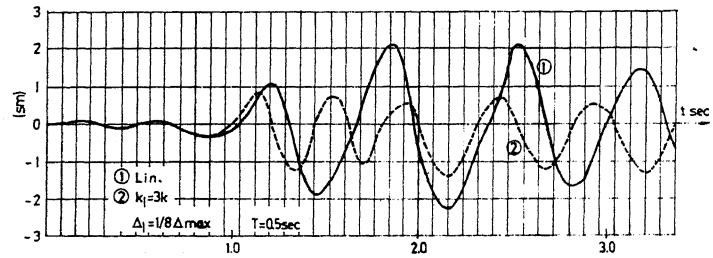
"Fig.5" Ancona earthquake of June 14,
1972,EOOW. Response to displacement



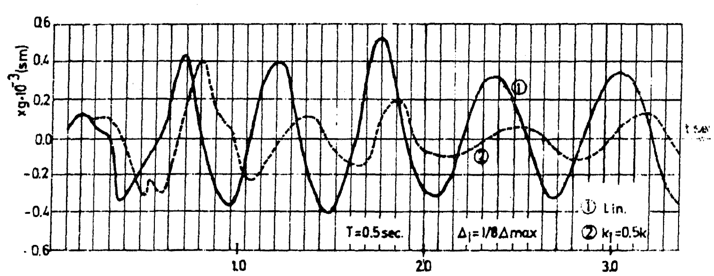
"Fig.6a" Parkfield earthquake of 1966,ST.2, response to displacement



"Fig.6b" Parkfield earthquake of 1966,ST.2, response to displacement



"Fig.7" Simulated earthquake Skopje "N", response to displacement



"Fig.8" Ancona earthquake of June 14,1972,E00W,response to displacement