PROGRESSIVE ULTIMATE ANALYSIS OF BUILDINGS OF ELASTIC-BRITTLE MATERIAL EXPOSED TO DYNAMIC EFFECTS

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Received: January 26, 1981

1. Introduction

Displacements of building structures of a linear-elastic material upon dynamic effects are described by a matrix differential equation written in general form as:

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{p}(t).$$

In knowledge of displacements, time-dependent stress variations can be determined. Displacements of buildings with a composite structure have of course a limit beyond that a given structural member does not exhibit even an approximate elasticity but yields or fails. When, however, a structural member gets in this state, rigidity, natural frequency of the complete system (structure) change, and so does its behaviour under dynamic load. In the following, this process will be investigated in detail.

2. Elastic-brittle material model

Analyses refer to an assumed elastic-brittle material model, justified by the increase of yield point under dynamic stresses, and the diagram referring to building structures is about of the form seen in dash line in Fig. 1, yielding, in turn, with further approximations, the rectilinear elastic-brittle behaviour in smooth line.

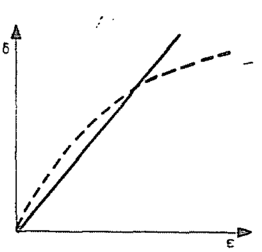

Fig. 1

3. Analysis of the process of progressive failure

The structural change due to a dynamic effect — affecting the natural frequency — may produce not only poorer but also better conditions for the subsequent stability of the building. It can be stated that dynamic effects on a structure have to be examined in connection with the behaviour of the load-bearing structure. In other words, development of the failure process belonging to the given load has to be examined, to decide to what a degree a given dynamic load is dangerous to the structure. Inversely, by modifying the failure process (reinforcing or weakening certain members) a load capacity providing adequate safety may be achieved.

Relying on this principle, further analyses have been made, assuming the elastic-brittle material model in Fig. 1. Furthermore, in connection with the failure process, the building was assumed not to collapse upon failure (yield) of some (maybe several) members but only upon failure of a number of members (determinable in actual cases). This may be a requirement of collapse

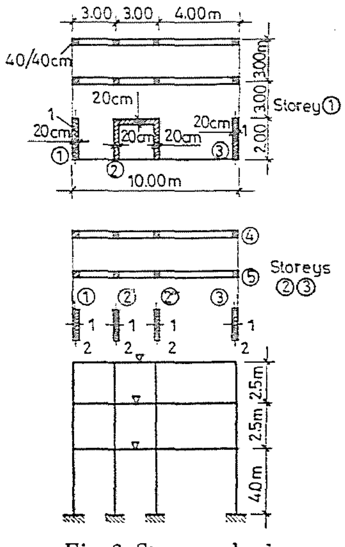

Fig. 2. Structural scheme

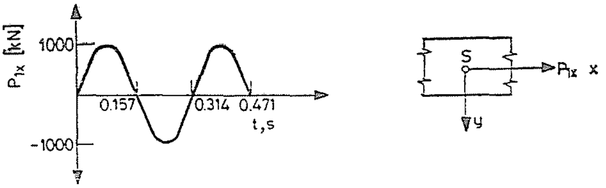

Fig. 3

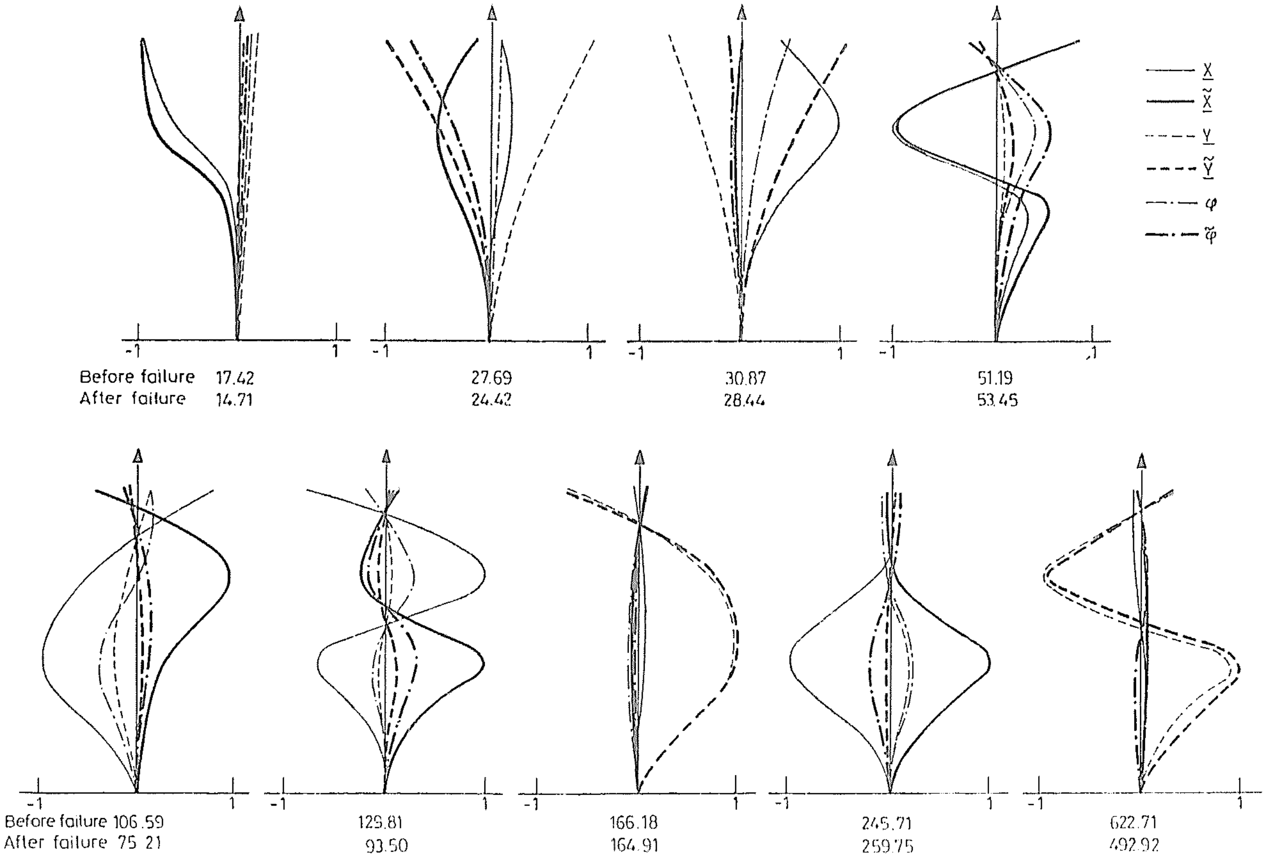

Fig. 4. **Natural frequencies and related normal modes**

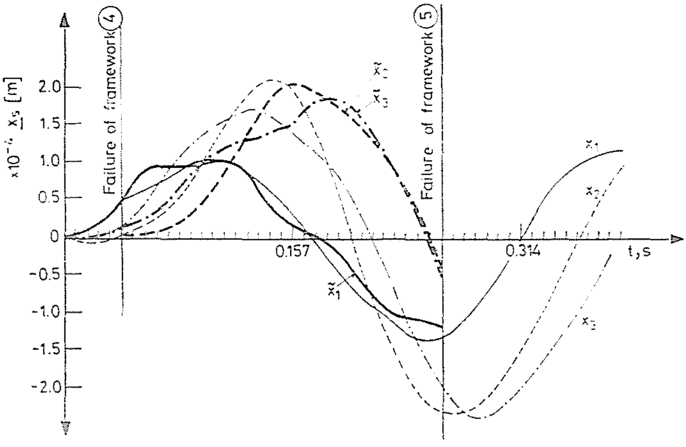

Fig. 5

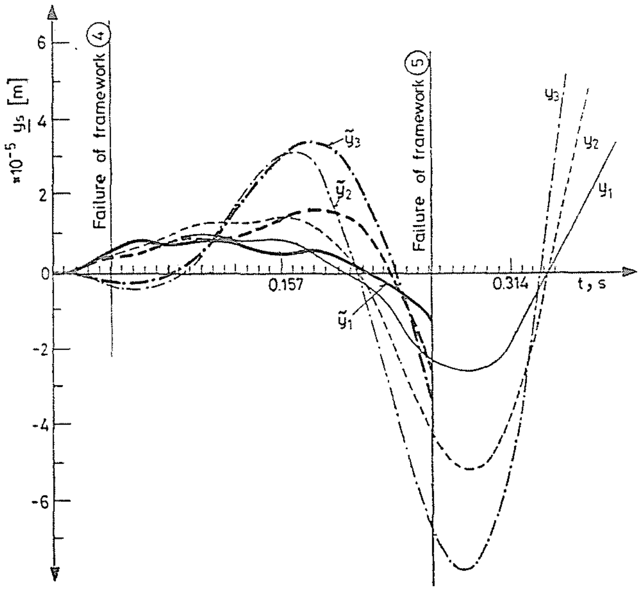

Fig. 6

safety for buildings exposed to seismic effects. The analysis proceeds along the following lines:

a) a load-bearing member on a storey of the building fails upon the action of dynamic load;

b) thereby the system rigidity changes and the changed system functions further on with initial conditions such as at failure;

c) the system changed after failure may behave so that it is exempt from further failures (in this case the structure is advisably designed so that missing of the failed member does not entrain collapse of the complete building);

d) in the event of another failure in the changed system, procedure under b) is repeated, and this analysis is continued until all members entering in a complete collapse fail.

Of course, this survey of the failure process may lead to an adequate structural solution exempt from collapse.

4. Numerical example for the analysis of progressive failure

A computer program has been developed for the described analysis, to be involved in the numerical illustration of the method. The tested building and the exciting force are those seen in Figs 2 and 3. Displacements causing failure in given members have been determined. Upon the effect of dynamic load, first the moment bearing of columns in the extreme framework failed. Natural frequencies and normal modes in this state of the changed building have been plotted in Fig. 4, together with the same values for the original

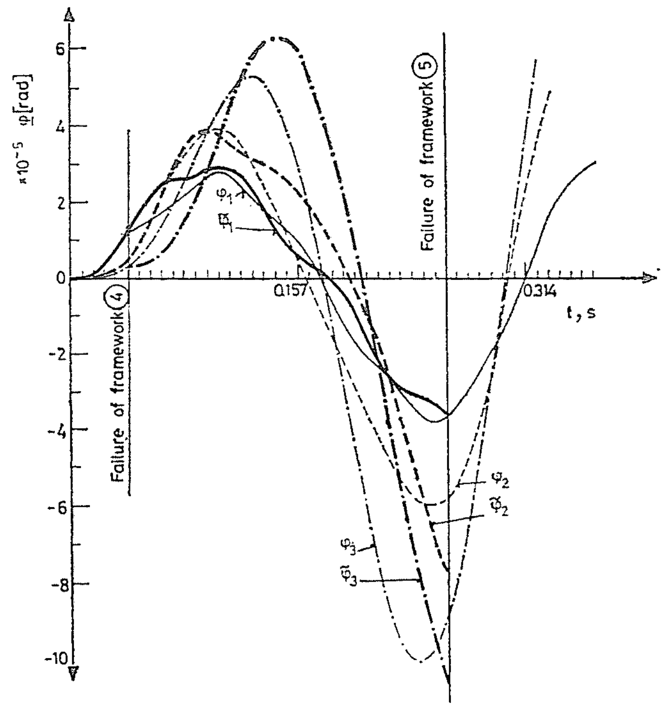

Fig. 7

(sound) structure. After weakening of the extreme framework, sound members of the structure continue to function, while after a time also the intermediate framework fails, entraining collapse of the building. Response curves of displacements x, y and φ are seen in Figs 5, 6 and 7 (displacements in the changed state are shown by curves marked $\sim$). In all three figures, also failure times are indicated. After the extreme framework fell out, structural motions are seen to have significantly changed compared to motions of the sound structure. Knowledge of the failure process hints to the inadequacy of the structure for the given dynamic load, and also to the way how to determine the method of sufficient strengthening.

In conformity with results of the numerical example, the presented method yields a comprehensive image of the effect of horizontal dynamic forces even for complex structures.

Summary

Collapse analysis of buildings with various structural systems starts from the correspondence between the dynamic load effect on the building and the structural behaviour. An elastic-rigid material model is assumed for calculating the collapse process, and the practical application is illustrated on a numerical example.

References

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2. VÉRTES, GY.—TORNYOS, Á.: Analysis of Composite Building Structures under Horizontal Dynamic Loads. Periodica Polytechnica C. E. Vol. 23. (1979), No. 2.

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* In Hungarian