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STUDY OF PROGRESSIVE COLLAPSE OF HIGH STRUCTURES IN CONNECTION WITH DEMOLITION BLASTING

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ABSTRACT:In connection with Demolition Blasting of a high structure, a study was made of the progressive collapse using high-speed motion picture photography. The structure was a ten-storied concrete-framed building located in Gothenburg, Sweden.

The building was demolished using explosives. During the blasting sequence the upper part of the building rotated around a point located at the back of the successively created V-shaped cut. This movement transformed into a vertical drop, while the structure was broken up from the bottom. Towards the end of the collapse the building was totally broken.

1. BUILDING DESCRIPTION

The structure was a ten-storied residential block erected in 1954 with the following characteristics:

- The height of the building was 33 m and the area 272 m².
- The total building volume was about 8160 m³.
- The floor construction was made of reinforced concrete of flat slabs with a thickness of about 160 mm while the main walls consisted of plain concrete with a thickness of 150 mm.
- The weight above the blasting cut was estimated to about 2800 metric tons.

The key map shows the blasting direction and the surrounding buildings, the nearest about 20 m from the blasting site (see figure 1).

2. DEMOLITION METHOD

The building was considered suitable for demolition by blasting due to its height and type of construction.

Demolition blasting means in this case to create a V-cut at the bottom of the building. The V-cut should be large enough to let the weight of the building make the construction to break into a manageable heap of debris, without creating hazardous vibrations in the surrounding buildings.

The height of the V-cut should at least include 2-3 floors in order to achieve adequate safety regarding direction and velocity of fall.

When blasting thin concrete constructions it is very often required to drill a large number of holes. To reduce the number of bore holes and consequently the number of charges required, the construction has been structurally estimated with respect to the possibility of making openings in advance in outer and inner walls on the floors where the V-cut will be made. With this method, the required amount of bore holes was limited to about 3000. Total amount of explosives was about 90 kgs with 25-40 grams in each bore hole. The distance between the bore holes was about 300 mm.

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The interval between the explosives charges was 25-150 milliseconds per delay and a total delay time of 1.9 seconds, see figure 2.

The principle of the blasting cut can be seen in figure 3.

3. HIGH-SPEED MOTION PICTURE PHOTOGRAPHY

The progressive collapse was filmed using four 16 mm high speed cameras with 500 respectively 64 pictures/second. The cameras were located on different places around the building. The purpose was to determine the position and velocity of separate parts of the building during the progressive collapse. This in order to calculate the energy absorbing ability of the construction. Special points on the fronts of the building and the camera positions were accurately measured and noted before blasting.

The film was analysed frame by frame. Predetermined measuring points, for instance a window corner, were registered on each photo and transferred to a computer using digitising equipment. All data from the digitising were computer analysed. By this, information was obtained about all the predetermined measuring points vertical position as a function of the time.

The resulting diagrams from the computer processing were drawn using a plotter. The horizontal axis shows the time and the vertical position of the measuring points.

The computer processing also gave vertical (and horizontal) velocity for each point and new diagrams were plotted. These diagrams showed the vertical velocity as a function of the time.

With information about the masses of the interacting co-operating parts of the structure together with functions of time/position and time/velocity it is possible to calculate the potential and kinetic energy as well as the total energy of the structure.

4. DESCRIPTION OF THE PROGRESSIVE COLLAPSE

The duration of the blast to open up the cut was 1.9 seconds and the possibility of filming before the dust from the blast concealed the building was 3.5-4.0 seconds. The progress can be divided into three phases:

Firstly: During the blasting sequence the upper part of the building is rotating because of the V-cut. Gradually it becomes a combination of vertical movement and rotation.

Secondly: During this phase, when the blasting sequence is finished, the progressive collapse has compressed the debris from the blasted cut and re-established contact with the bedding. A decelerating effect builds up while the counter force in the structure is broken from the bottom. The rotation has ceased, a settlement is taking place and the part closest to the cut is breaking up.

Thirdly: During phase three the whole building is cracked up all the way to the roof simultaneously as the dust cloud stops further studies of the collapse mechanism.

5. RESULT FROM THE HIGH-SPEED MOTION PICTURE PHOTOGRAPHY

Phase 1. During the time for blasting the cut there was no connection between the structure above and below the cut. During the blasting sequence the building was rotated around a point A, located at the back of the V-shaped cut (see figure 4).

The distance between the structures was reduced until new contact with the bedding was reached. The floors nearest the cut were

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somewhat cracked, while the other floors still were intact. The acceleration in most of the measuring points was in this phase about 1 g, which means almost free falling (see figure 5) where the left line = 1 g and the other curves show the acceleration for the points 2,4,6 and 11 on the front of the building. First free falling, than decreasing velocity and at last the velocity increases again.

Phase 2. When the last charge was detonated the rotation of the building stopped. The energy which then existed to break down the structure was only the potential and kinetic energy from the building itself. Therefore the motion was decelerating simultaneously for the whole building and the velocity decreased.

The falling building moved towards the street and was coming down outside the basement walls. The falling walls, however, broke down successively against the underlying collapsed debris. The building was still almost intact in the upper floors.

Phase 3. The counter force in the structure has diminished more and more and the velocity has accordingly increased again. The whole building collapsed before the dust concealed the ruin.

6. COLLAPSE LOAD

The total energy, E, is constant at free fall.

$$E_p + E_k = \sum mgh + \sum \frac{mv^2}{2} = \text{constant}$$

E_k = kinetic energy
E_p = potential energy

When you do not have free fall the energy in the system will decrease. The lost energy from the system is used to break down the structure and to emit heat (see figure 6).

Typical for the energy curve of a structure, which can stop the progressive collapse, is that the kinetic energy E_k is low during the whole progress and that the energy curve is flattening out while there still is a lot of potential energy (see figure 7).

When using demolition blasting, the building must obtain large enough kinetic energy. The structural elements must be cut off by blasting so that the counter force does not have the strength to stop the collapse before it is completed. On the other hand, the kinetic energy must not be so high that harmful shocks or vibrations will be created in surrounding buildings.

The total energy for the actual building - see figure 8.

The total counter force is estimated at the upper level of the ground floor. The acceleration (see figure 9), is calculated from the velocity diagrams.

Total counter force P.

$$\sum m_1 (g-a) - \sum P = 0$$

m_1 = pushing mass

The total counter force per cross section area of the walls can be seen in figure 10.

Collapse load $q_{collapse}$
m_2 = mass of crushed debris upon the ground floor.

$$\frac{\sum m_1 \cdot (g-a)}{A} + \frac{\sum m_2 \cdot g}{A} = q_{collapse}$$

A = area of the ground floor

The collapsed load has been calculated at the upper level of the ground floor (see figure 10).

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REFERENCES

Dellgar, U and Westling, I 1990. *Study of progressive collapse, Kortedala. Blasting demolition.* FoU report *P-21-010/90. In Swedish. National Rescue Services Board.*

Sjöberg, C 1986. *Mini-hole blasting practised in concrete blasting. Proc. Swedish Rock Blasting Committee, Discussion. Meeting BK-86:197-218. In Swedish.*

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Figure 2 Ground plan and ignition pattern

Figure 1 Keymap

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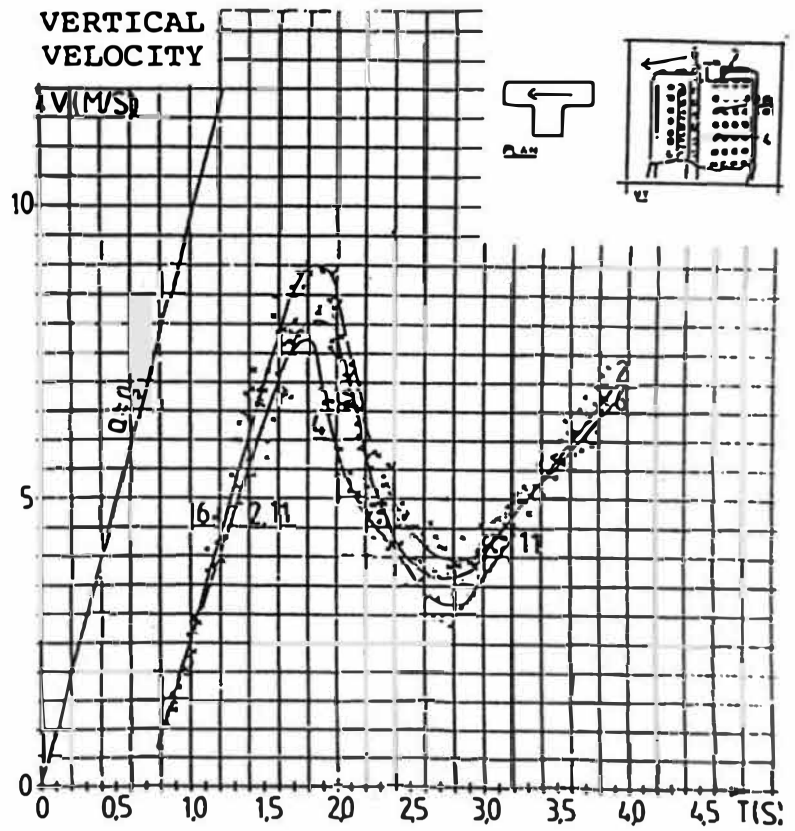
Figure 4

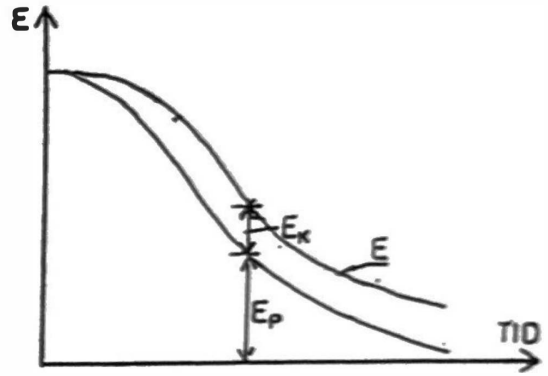
Front view and blasting cut

Figure 3



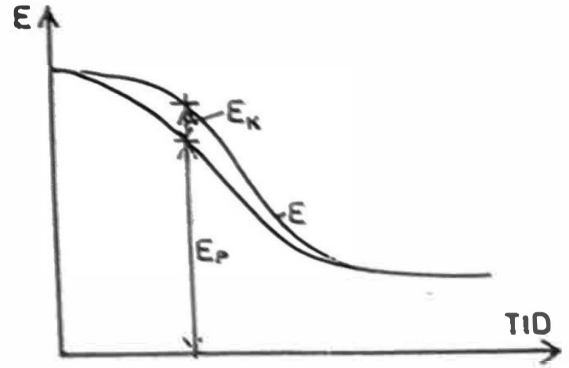
Vertical velocity

Figure 5



Typical energy curve wher the collapse can stop

Figure 6



No free falling

Figure 7

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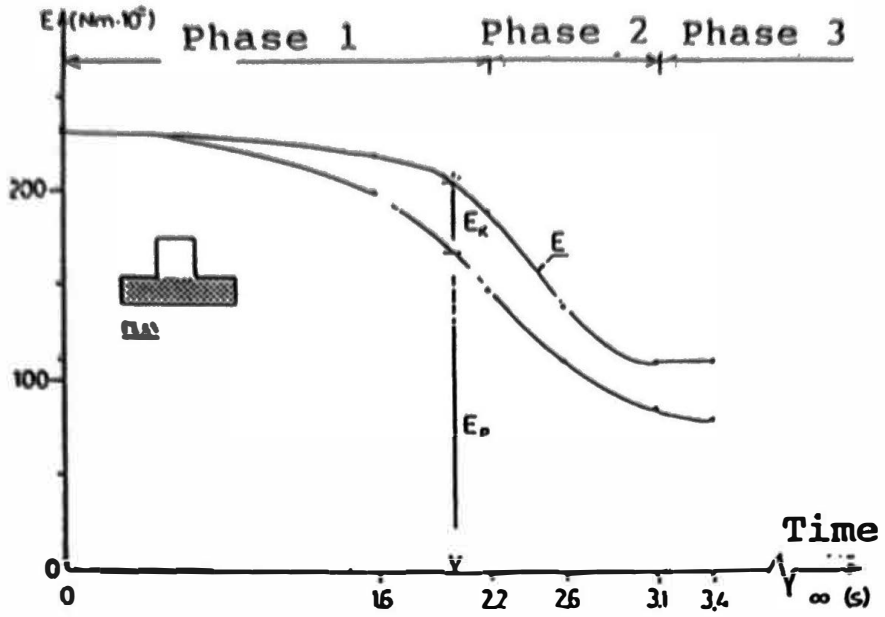

Total energy

Figure 8

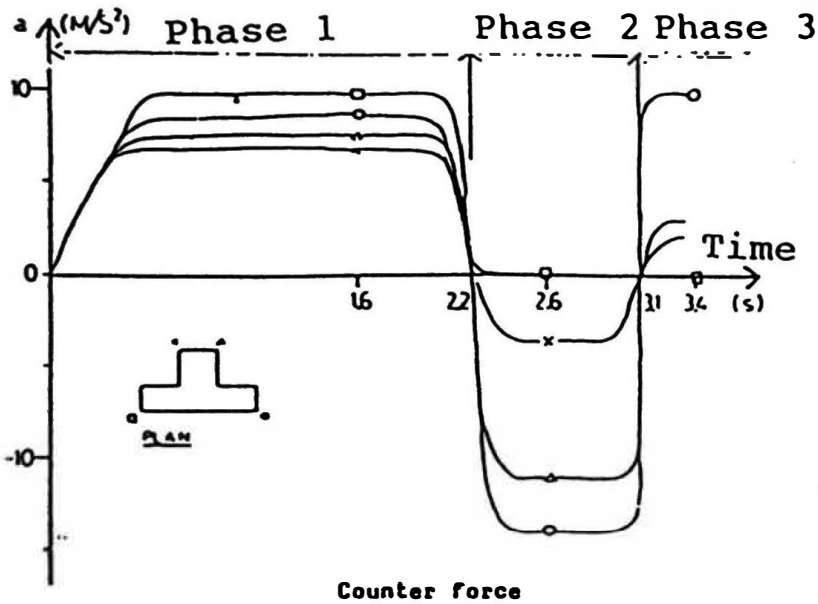

Figure 9

Counter force

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Figure 2 Ground plan and ignition pattern

Figure 1 Keymap

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Figure 4

Front view and blasting cut

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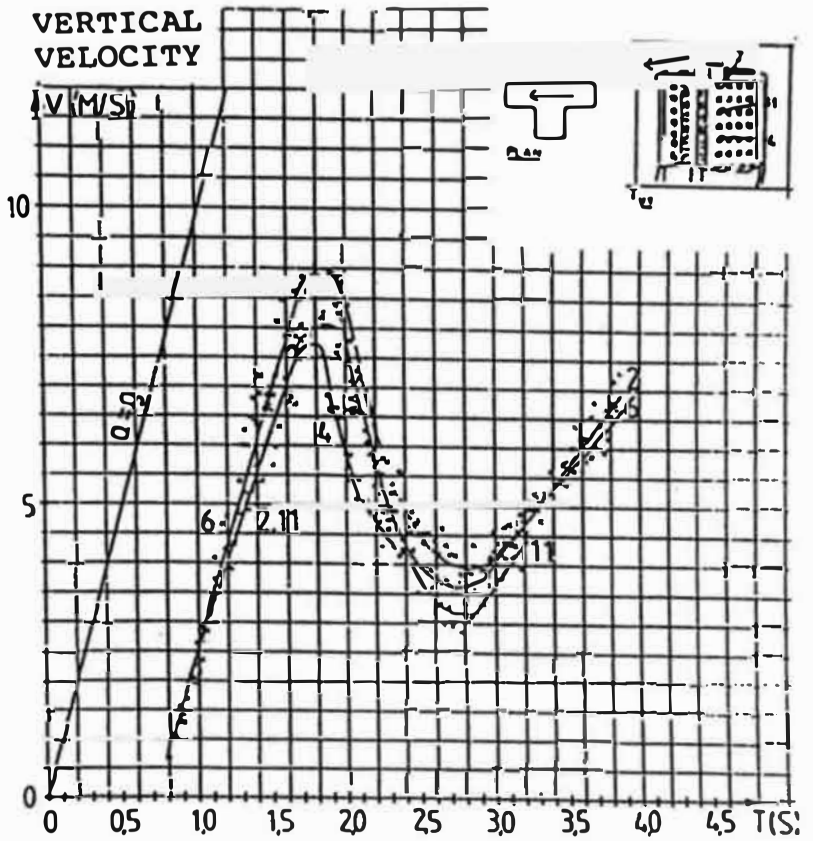
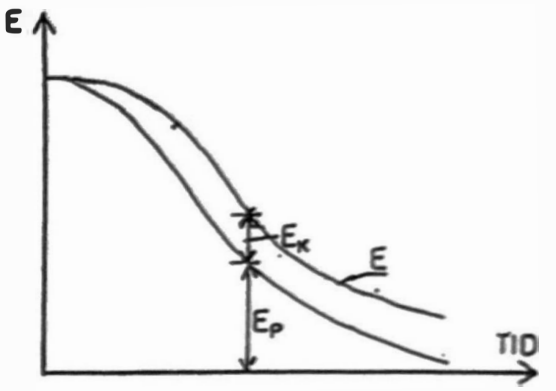


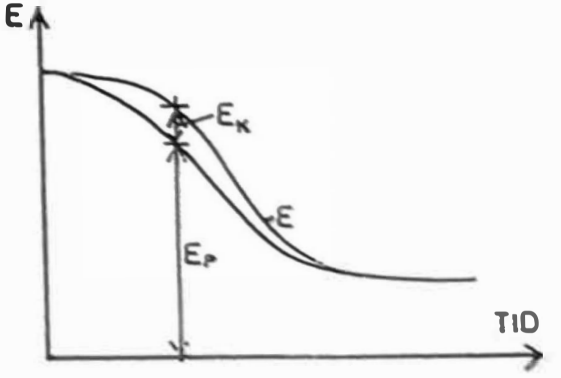
Vertical velocity

Figure 5



Typical energy curve where the collapse can stop

Figure 6



No free falling

Figure 7

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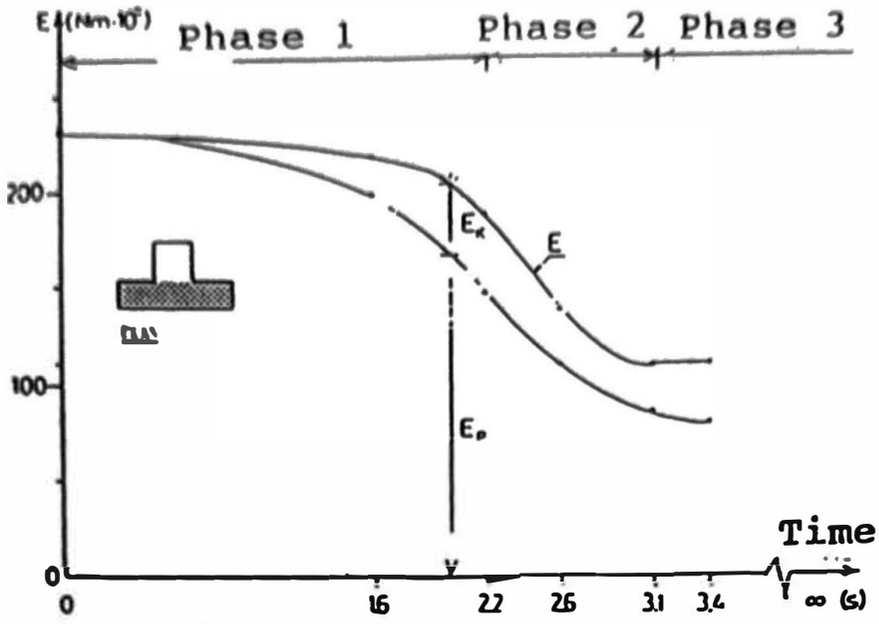
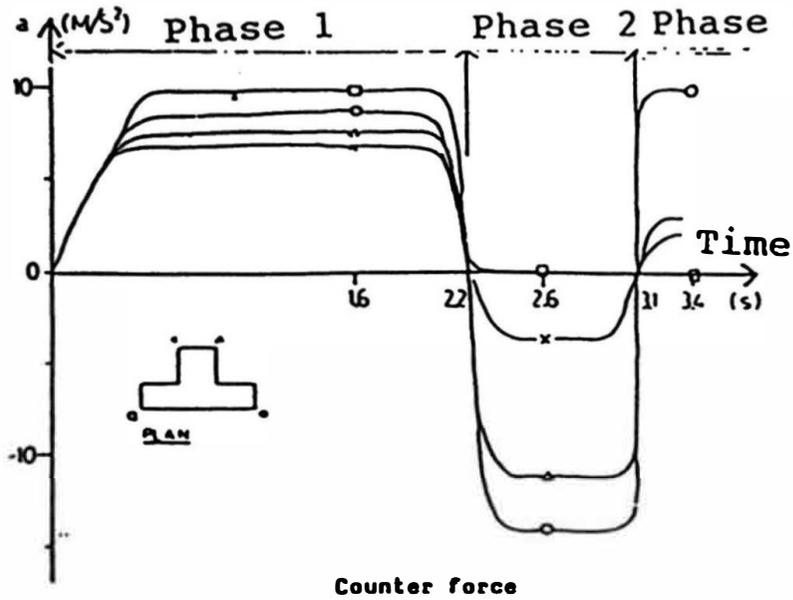


Total energy

Figure 8



Counter force

Figure 9

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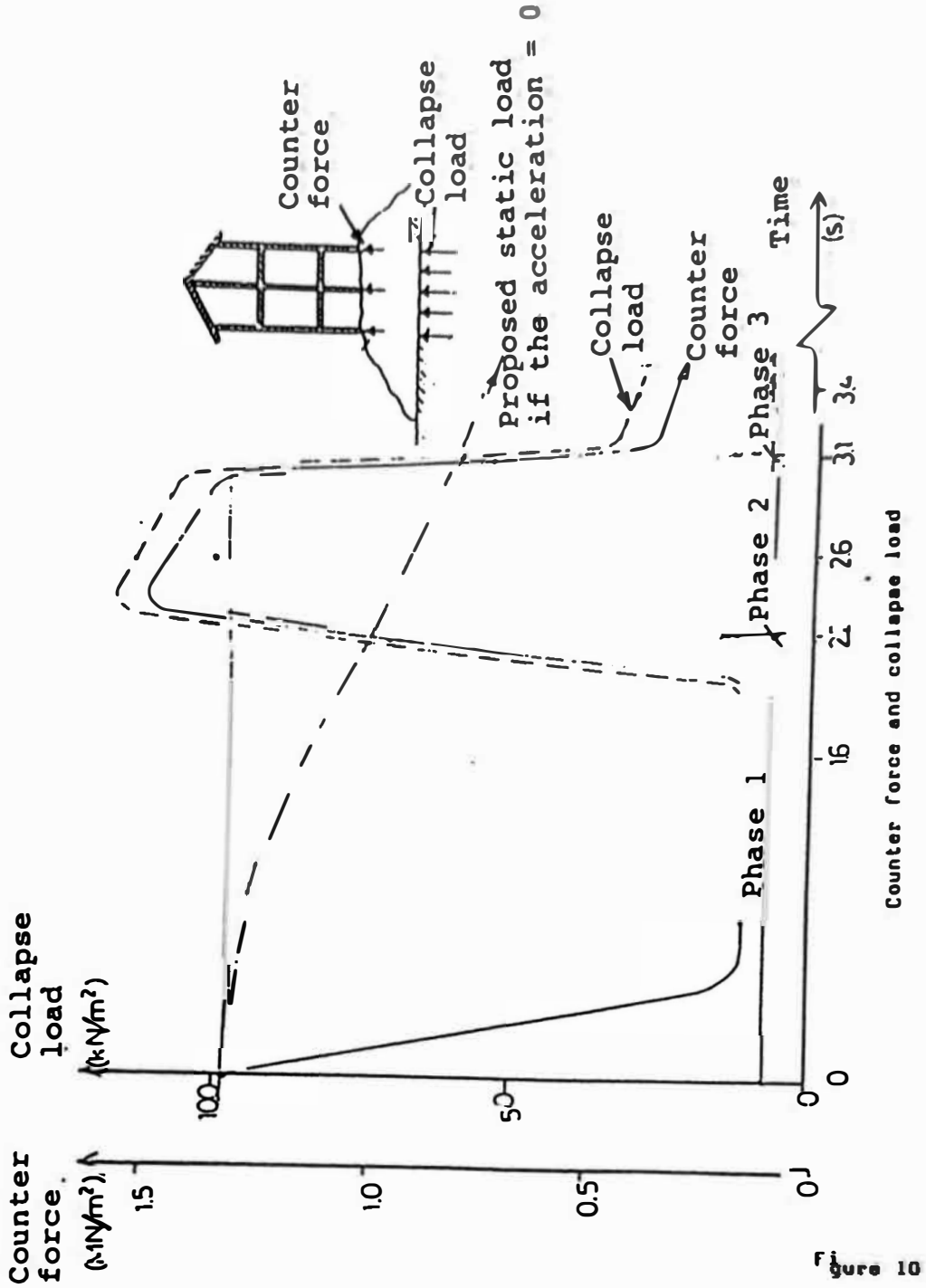

Counter force and collapse load

Figure 10