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Energy Absorption Capability of Slabs with Different Reinforcement Steel

Capacité d'absorption d'énergie de dalles en béton avec différentes armatures

Energieaufnahmefähigkeit von Betonplatten mit verschiedener Bewehrung

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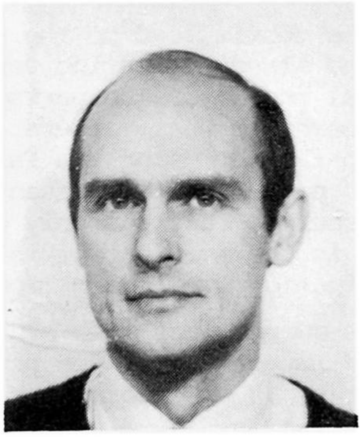

Lars Andersson, born 1947, received his civil engineering and licentiate degree at the Royal Inst. of Technology. Since 1969 he has been working in the field of building construction. In 1983 he started research work with the aim of determining debris loads on shelters.

SUMMARY
One-way reinforced concrete slabs with different types of reinforcement steel have been loaded in impact by a free falling drop weight of steel. The aim was to study how different reinforcement steel influence the capability of the slabs to absorb energy. The dissipated energy was estimated by comparing the sum of potential and kinetic energy before and after impact. Positions and velocities of the slab and drop weight were determined with a high speed camera in order to calculate the energy after impact.

RÉSUMÉ
Des dalles en béton armé renforcées dans une seule direction mais avec différentes armatures ont subi les chocs d'une masse d'acier en chute libre. L'objectif de l'étude était de voir l'influence des différentes armatures sur la capacité d'absorption d'énergie de ces dalles. L'énergie dissipée a été calculée en comparant la somme des énergies potentielle et cinétique avant et après le choc. La position et la vitesse de la masse métallique et de la dalle ont été déterminées avec un appareil photo à haute vitesse, afin de calculer l'énergie après le choc.

ZUSAMMENFASSUNG
In einer Richtung gespannte Betonplatten mit verschiedener Bewehrung wurden mit einer fallenden Masse aus Stahl stossbelastet. Das Ziel war es, den Einfluss verschiedener Bewehrungsstähle auf die Energieaufnahmefähigkeit der Platten zu bestimmen. Die kinetische und potentielle Energie vor und nach dem Stoss wurden mit einer Hochgeschwindigkeitskamera bestimmt. Der Unterschied der Energie vor und nach dem Stoss ist gleich der Energieaufnahme der Betonplatte.

1. INTRODUCTION

To protect civil people from damages in war, shelters are built. The shelters are often placed in the basement of a building. To design the shelters one first have to decide what kind of loads the shelter shall be designed for. The Swedish formula code says that two loads as a result of war actions are to be considered: first, the shock wave from an exploding bomb and second, the debris load from the collapsing buildings.

The author has since 1983 studied how to calculate the debris load. The aim was to divide buildings into different types depending on their capability to reduce the debris load.

Briefly one can say that the debris load on the shelter will be a function of the mass of the building and its distribution vertically above the shelter-roof. In other words the potential energy of the parts of the building that can be transformed into kinetic energy is what matters. The collapse of the building is assumed to start at the top floor. During the fall energy losses will occur when the building is broken into parts. In the present Swedish code formula used to calculate the load on the shelter-roof the only energy loss during the collapse that is taken into account is the energy that is needed to fail the floor slabs in flexure and energy dissipation at plastic impact.

To estimate and compare the energy loss when slabs are loaded to ultimate failure, several static and impact tests were performed and reported in [1] and [2]. In the tests different types of slab strips and loadings were used.

It was found that in slabs with the reinforcement arranged so that membrane effect could occur the energy dissipation to exhaust the bearing capacity was very high compared with slabs with only bending moment.

The consequence of this for calculating the debris load on shelters is that buildings could be separated into two parts. One with only flexure moments in the slabs and one where the reinforcement is arranged so that membrane effect more or less can occur. In buildings with membrane effect the debris load will be smaller.

Different kinds of reinforcement are used in practice. It would therefore be of great interest to compare how the choice of different reinforcement steel influence on the energy dissipation when a slab with membrane effect is loaded to ultimate failure. Impact tests on slabs with different reinforcement steel were carried out and are reported in [3] and [4]. A summary of this research work is given here.

2. TEST SPECIMEN

Mainly four kinds of reinforcement steel were used. They had the notations Ss26S, Ks40, Ks60 and NPs50 and are frequent in Sweden. S stands for plain bars, K stands for deformed bars, sxx stands for nominal yield strength in kp/mm^2, S in the end stands for weldable.

The slabs had the dimensions: length 1,96 m, width 1,20 m and depth 0,1 m. (An example can be seen in fig 1). The number of reinforcement bars was chosen so that the same total tensile force in the slabs was attained independent of the type of reinforcement steel. The calculation of how many bars each slab should have was based on the yield force of a single bar. The total force in the slab was 210-220 kN. Totally 34 slabs were tested.

3. PERFORMANCE OF THE TESTS

The load was a free falling drop weight of steel. The mass of the drop weight was one ton which was twice as much as the mass of the slab. The drop weight

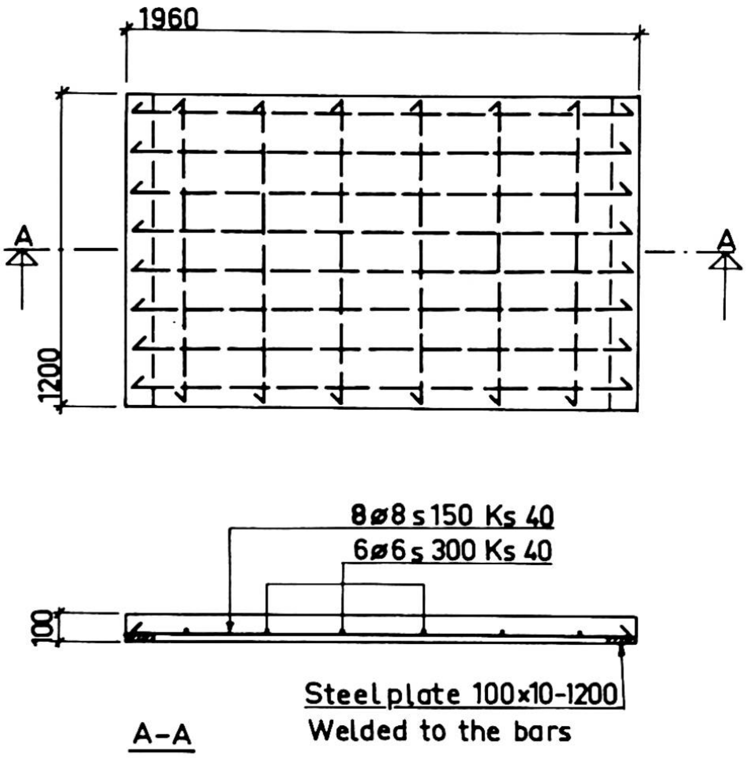

Fig.1 Test specimen.

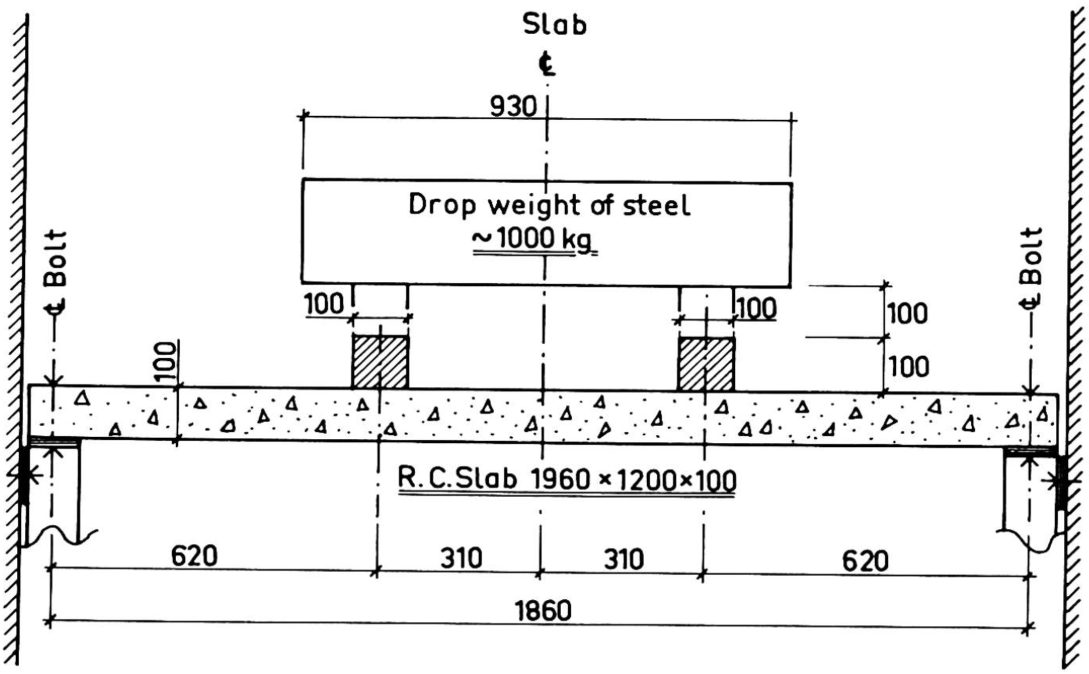

Fig.2 The drop weight standing on the test specimen.

standing on the plate is shown in fig 2.

The drop heights were mainly 4, 8 and 11 meters. In the case of 4 m the drop weight was stopped or nearly stopped if the reinforcement was Ss26S, Ks40 or Ks60.

4. ANALYSIS OF THE TESTS

The tests were filmed with a high speed camera (~500 pictures/sec). On the films the course of events could be followed. With help of the films, the kinetic and potential energy was calculated when positions, velocities and masses of the drop weight and plate were known. These energies were compared with the initial total energy for the drop weight slab system to get the energy dissipation during the time it took to exhaust the bearing capacity of the plate. See one example in fig. 3.

The remaining strain of the bars after the impact tests was measured. This strain was about 15 to 40 % of the limit strain. The limit strain is the strain at maximum force in tensile tests on reinforcement bars.

The theoretical modelling of the test was done by replacing the real drop weight/slab system with an equivalent mass-spring system. The equivalent system has the same characteristics concerning energies and work done under the deformation as the real system. Data from the tests were used to verify the calculation model.

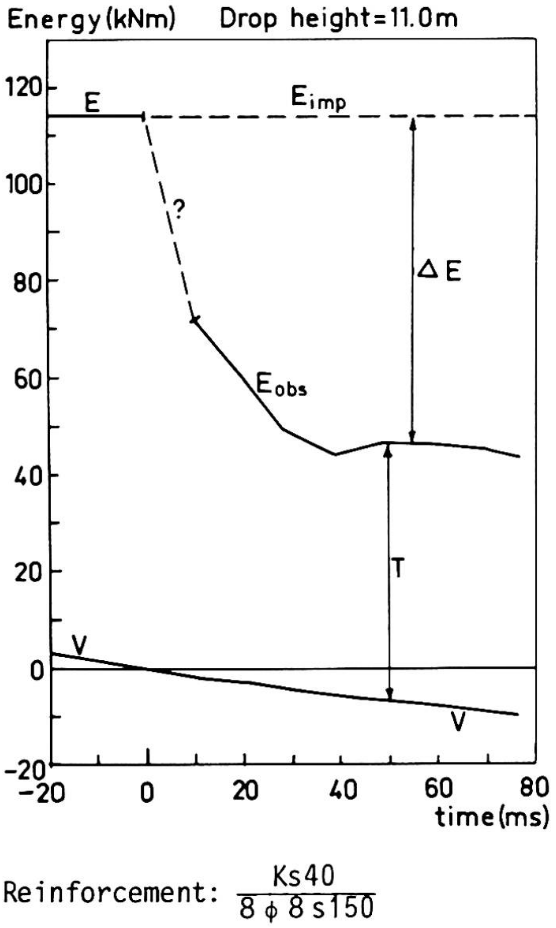

Fig.3 Comparison between the sum of potential and kinetic energy before and after impact.
Time at impact = 0.
V = Potential energy. Zero at impact.
T = kinetic energy.
E_{imp}=V+T at the moment of impact.
E_{obs}=Observed sum of V and T after impact.
ΔE = Energy dissipation. (= E_{imp} - E_{obs})

5. RESULTS

The relation between energy absorbed in the whole plate (with different kinds of reinforcement) was, if the energy absorbed in plates reinforced with Ks60 is set to 1,0:

Drop height (m)	Ss26S Φ8	Ks40 Φ8	Ks60 Φ8	NPs50 Φ6
11 m	1,9	1,2	1,0	0,65
8 m	2,6	1,4	1,0	>0,45

An estimation of the relation between energy absorbed in the reinforcement bars was, if the energy absorbed in Ks60 is set to 1,0:

Drop height (m)	Ss26S Φ8	Ks40 Φ8	Ks60 Φ8	NPs50 Φ6
11	2,7-2,5	1,7-1,4	1,0	0,6-0,5
8	3,0-2,8	1,7-1,5	1,0	-
4	(2,3-2,1)[1]	2,0-1,7	1,0	0,5-0,4

[1] Should be higher because the ultimate strain was not reached.

It is seen from the first table that it is possible to rank the reinforcement after its capability to absorb energy. The plain bar Ss26 is best. The ranking is the same as if you would have compared the limit strain of the bars. You could also see from the two tables that an increased drop height makes the difference in energy absorption capability smaller.

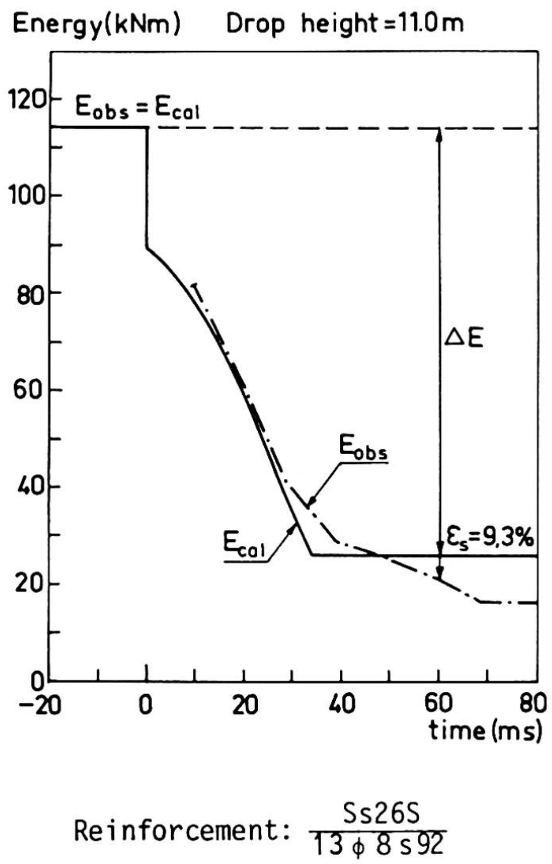

Fig.4 Comparison between observed (E_{obs}) and calculated (E_{cal}) sum of potential and kinetic energy. Time at impact = 0.

ΔE = Energy dissipation.
ε_s = Measured ultimate strain in the reinforcement bars.

The extended drop height also gave an increased energy dissipation. The reason for this is that the plates are broken into smaller parts and therefore the reinforcement loses the surrounding concrete. Free reinforcement bars have higher strain capability than bars embedded in concrete.

The theoretical estimation of the sum of kinetic and potential energy shows good agreement with the energy from the tests. See one example in fig.4. The calcula tion of the energy dissipation is stopped when the calculated remaining strain in the bars is equal to the observed remaining strain in the plates. A high value of the tensile force of the bars is presumed.

6. ACKNOWLEDGEMENT

This work has been done under the guidance of my teacher Professor Sven Sahlin.

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