The History of the Falling Weight Deflectometer (FWD)

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In 1964 the possibilities of the FWD for bearing capacity measurements were examined for the first time in Denmark. Two dissertation projects were among other things the start of a new company and international acknowledgement. Former senior lecturer at the Technical University of Denmark (DTH), Mr Axel O. Bohn tells about the development of the falling weight deflectometer during 25 years.

Some time during the year of 1964 Professor Thagesen, at that time working for the Danish Road Laboratory, telephoned the author and suggested that a student could investigate a falling weight deflectometer for bearing capacity measurements as his dissertation project. The falling weight deflectometer was constructed at the Danish Road Laboratory, but the laboratory could not find time for the testing of the equipment. The research work was split up into two projects: One carried out by Mr Finn Hansen in 1964 (1) and one carried out by Mr Per Ullidtz and Mr Michael Gautier in 1965 (2). A pilot study made with the device of the Danish Road Laboratory showed that as to the load cycle, this device was inferior to devices constructed by the French Road Laboratory (3), (4) which we were reading about at that time. The French tests showed that with a falling weight device consisting of a mass which was dropped on an undamped spring, the considerable mass of the spring would complicate the force cycle during testing. One solution appears from Fig. 1. The weight was dropped on a system consisting of two springs with a mass inbetween.

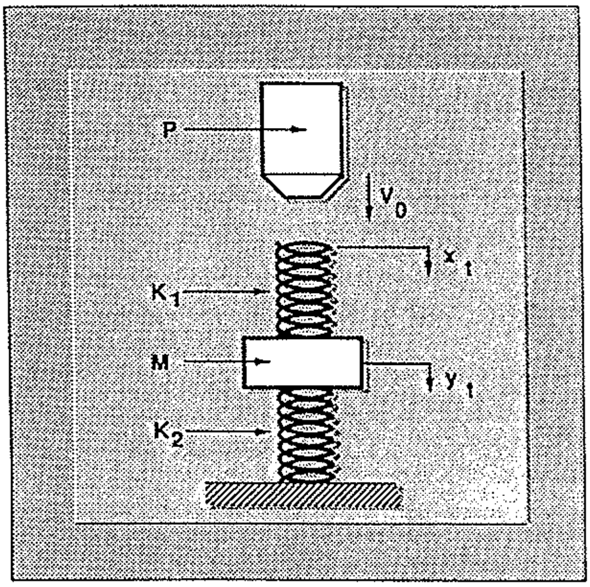

Fig. 1: Falling weight with mass between 2 springs

The desired aim was reached: The shape of the force cycle was a sine curve. The principle has been further developed and applied for a Swedish constructed FWD (5). The impact time would not go below 40-50 msec. under the French tests thus, the French researchers chose to apply a combination of a spring and a damper (Fig. 2). In this way impact times of 28 msec. were reached as a better simulation of the load of a fast running wheel.

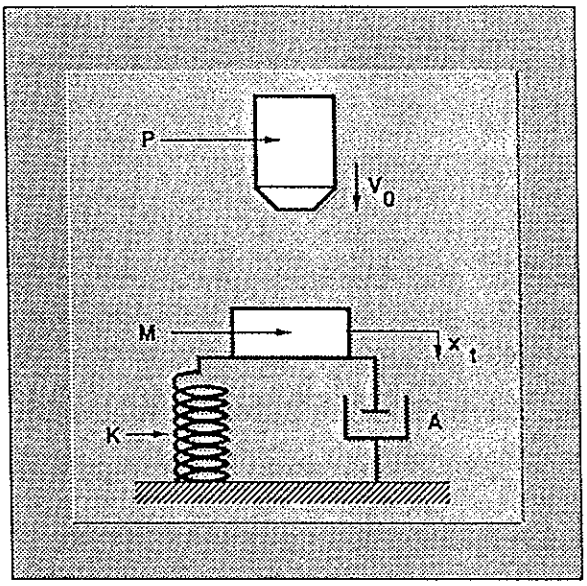

Fig. 2: Falling weight with damped spring

On the basis of the French information, the device in Fig. 3 was constructed at DTH.

The 150 kg weight F is hoisted 40 cm with the shown handle and fastned on top of the central column E with a release hook. When the hook is activated, the weight will dropp and hit three special s-shaped combinated springs and dampers transmitting the force to three hollow columns C with straingages for measurement of the load signal.

The columns are fastned below to a rubber covered plate (30 cm Ø). In the middle is a hole in which the point of the sensor of a deflection meter held by hands is situated. The deflection of the sensor is magnified 5 or 20 times and a pin scratches the signal on a wax paper tape which is driven forward by a small electric motor.

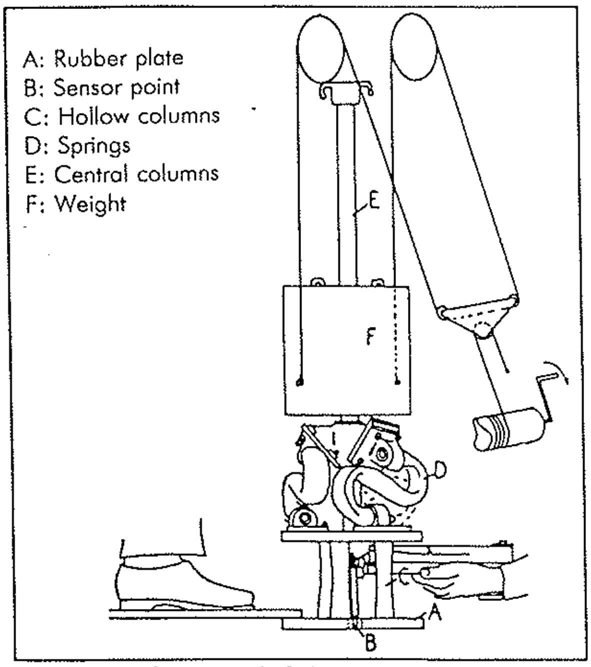

Fig. 3: The first Danish falling weight

The first falling weight deflectometer was not very easy to operate. One held the deflection meter steadily while the heavy weight passed by one's head. It was not easy to transport either.

Therefore it was a tremendous advantage when Civil Engineer J. B. Villadsen succeeded in making his company A/S Phønix construct a series of falling weight deflectometers in a more handy version. Mr Villadsen was a member of a study group led by Professor Ravn at the Technical University of Denmark and here he was introduced to the falling weight deflectometer. (Fig. 4).

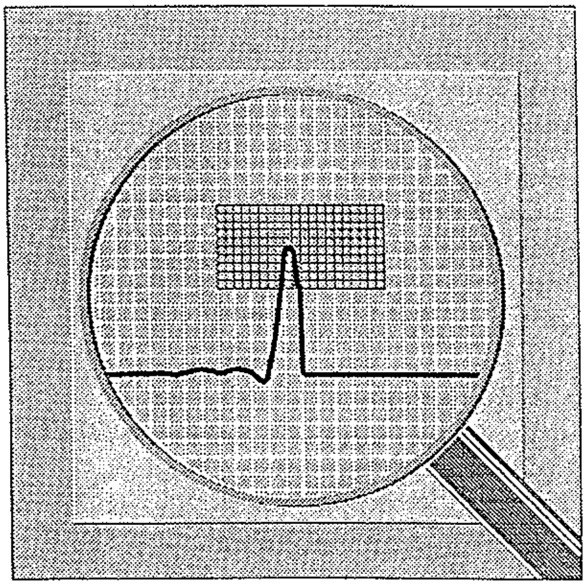
Fig. 4: Phønix' first falling weight deflectometer

65 falling weight deflectometers were constructed. The first ones were produced in 1968-1969. In 1975 the S-shaped springs, whose lives had turned out to be limited, were replaced by 3 rubber buffers. Tests showed that also this arrangement produced the desired load cycle. The weight was lifted hydraulically with a hand pump. The arrangement was mounted on a trailer. During transport the lifting arrangement could be laid down. The deflection was measured electronically. For the tests at the Technical University of Denmark a socalled LVDT (linear variable differentical transformer) held by a lattice beam was applied. The movement of an iron core in a coil is transformed into a voltage proportional with the deflection. (Fig. 5).

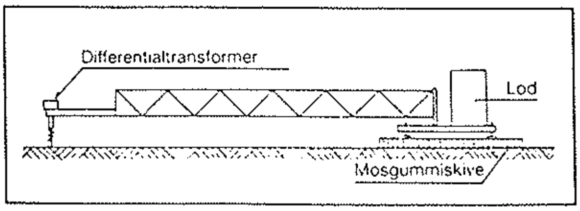

Fig. 5: Differential transformer with suspension

In France the falling weight test had been stopped as they preferred to stake on the French wandering Benkelman Beam, the Lacroix deflectograph. The English road laboratory was not interested in the falling weight deflectometer. Their expert, Mr Throver explained to me, when he visited me, that the falling weight deflectometer did simulate the same load cycle on the surface as a fast running car wheel, but that the load in the lower layers would be extremely short under the weight. Furthermore the inertia in the moved road materials had an influence by the falling weight tests - at velocities below the velocity of sound in the road structure, French tests (6) had shown that the inertia forces did not influence as regards running traffic.

These considerations led to some very thorough Danish comparing measurements with falling weight deflectometers and fast running wheels.

In his dissertation of 1973 (8) Mr Ullidtz treated the problem falling weight/car wheel thoroughtly. The experimental work was on two instrumented test roads with full depth asphalt constructions to compare the surface deflection and the vertical stress and the horizontal strain at the top of the layer below the asphalt layer within a temperature range of 0-35 oC when influenced by a) a fast running heavy trunk wheel, b) a falling weight and c) a Benkelman test.

From Fig. 6 it appears that the surface deflections under the car wheel and the falling weight are identical within the entire temperature (and thus deflection) range, but the Benkelman measurements deviates considerably at higher temperatures where the asphalt is softer. The measurements of the vertical stress and the strain at the top of the unbound layer showed the same: No difference between falling weight and car wheel.

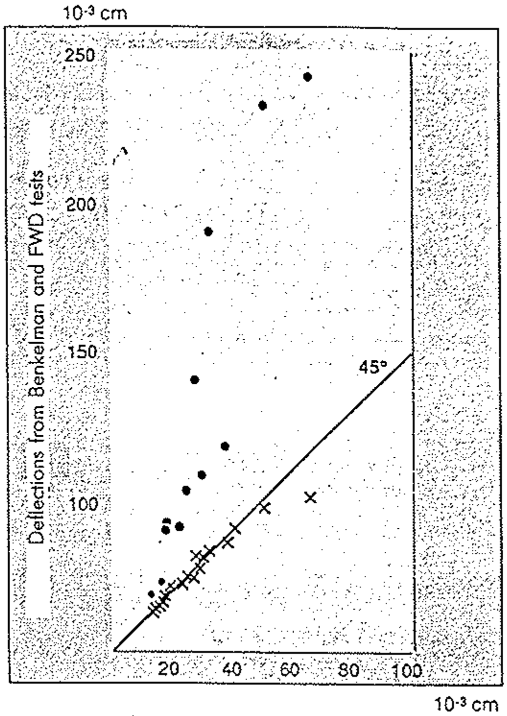

Fig. 6: Deflections
Abscissa: Wheel load
Ordinate: x falling weight, • Benkelman

Shape of Deflection Bowl

By the first tests with the falling weight, only the centre deflection was measured. 60-80% of the deflection was due to the subgrade. Thus the centre deflection can only tell little about the other layers - more data can be collected when the shape of the deflection bowl is known. In 1969 Mr Dehlen (9) mentioned that he in connection with a Benkelman measurement should combine the determination of the deflection with a measurement of the radius of curvature. For a number of roads Mr Dehlen thus found better correlation between crack frequency and high deflection figures. A great step forward was in 1970 when Mr Walkering (Shell) (10) suggested to measure the deflection at the centre of the plate and at the distance 2a - a being the plate radius. He had developed a diagramme with a computer calculation program for linear elastic layer systems reaction on a load, which allowed calculation of the E-moduli for a two-layer system with known layer thicknesses. Mr Ullidtz elaborated on Mr Walkering's idea and in 1974 (11) he suggested to measure the deflection at the centre of the plate and at the distance 2a and 5a from the centre. Today the commercial falling weight deflectometers are delivered with beams with 6 or 7 geophones for deflection measurement at various distances. With additional equipment the number of geophones can be increased to 9.

Until 1979 when Dynatest manufactured falling weights themselves, Phønix could draw on the electronic expertice of Dynatest for measuring equipment for the Phønix falling weight deflectometer consisting of a load cell and three geophones with digital output of load and deflection. Later Phønix bought know-how from the Technological Institute of Denmark. In 1981 Phønix could offer a system with one load cell and 6 geophones. As an answer to Dynatest's falling weight deflectometer type 8001 from 1979, Phønix could in 1984 offer a new falling weight the ML10000.

Figures 7 and 8 are sketches of the falling weight parts themselves.

Pavement Management PM

Authorities that are to plan the maintenance of a road network within a given budget limit can benefit from having the network measured by a falling weight.

In brief; information on the road condition is collected visually, the geometric data, evenness, road structure and bearing capacity (falling weight results) and traffic load. The road network is devided into uniform sections and for each section the costs over the years are calculated for maintenance carried out by means of a number of alternative solutions. For each solution the costs are discounted back to the time of initiation. An analysis can be carried out for the entire road network showing the cost/benefit ratio by raising or reducing the means available for the roads. If the data base is updated at intervals, the security is increased.

The main reason for installing a PM System in a road authority should not be a wish to have the allocations increased but a wish to obtain a better and more economical use and control of the means that are available and to be able to point out consequences, document and explain the decisions made.

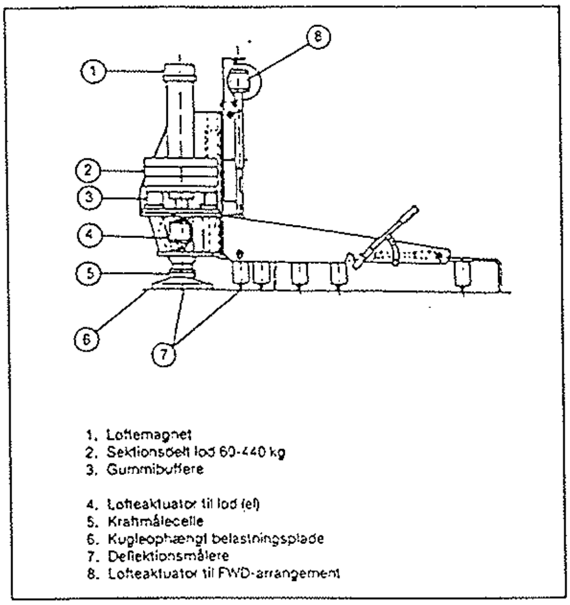

Fig. 11: Phønix FWD ML10000

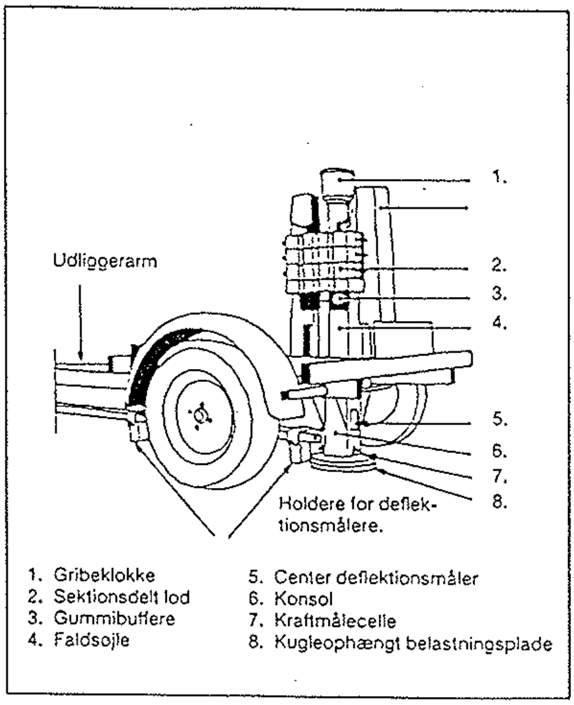

Fig. 12: Dynatest FWD 8001

Bibliography

1. Finn Hansen: " Curvature Measurement, Dynamic Plate Loading" Dissertation work IVTB 1964.

2. Per Ullidtz and Michal Cautier: "Dynamic Plate Loading Tests. Velocity of Sound Measurements" Dissertation work IVTB 1965

3. M. Bretonniere: "Etude d'un Déflectomètre à boulet. Bulletin de liaison des Laboratoires Routiers. 1963, No. 2 p. 43-50.

4. Ph Léger: "Etude experimentale en 1964 d'un déflectomètre à boulet et à ressorts Jarret". Bulletin de liaison des Laboratoires Routiers 1964, No. 7 p. 8-1.

5. O. Tholen, I. Sharma, R.L. Terrel: "Comparison of Falling Weight Deflectometer With Other Deflection Testing Devices" Transportation Research Record No. 1007, T.R.B. Washington D.C. 1985, p. 20-26

6. A. Avramesco: Quelques notions theoriques relatives à la dynamique des chaussees. Bulletin de liason des Laboratoires Routiers 1965, No. 14, p. 2-12.

7. A. Bohn, P. Ulllidtz, R. Stubstad, A. Sørensen: "Danish Experiments with the French Falling Weight Deflectometer, Third International Conference on the Structural Design of Asphalt Pavements Vol. 1, 1972 p. 1119.

8. P. Ullidtz: " A Study of two Full Depth Asphalt Pavements", Copenhagen 1973.

9. G.L. Dehlen: "An Investigation of Flexure Cracking on a Major Highway", International Conference on the Structural Design of Asphalt Pavements 1962, p. 11-109.

10. C.P. Walkering: "Pavement Evaluation by Measuring Deflection and Shape of Deflection Bowl", Third International Conference on the Strutural Design of Asphalt Pavements.

11. P. Ullidtz: "Some Simple Methods Determining the Critical Strains in Road Structures", DTH 1974.