

# PRIMA 100 FWD

Comparative measurements and experience with the portable PRIMA light FWD



## **CONTENTS**

### **1. Introduction and background**

Measuring equipment

Static plate bearing testing equipment

Static plate bearing testing is done in the following ways

The general method

The Danish method

The Swedish/German method

Bearing capacity measurement with heavy FWD

Measuring with FWD is done as follows

Bearing capacity measurement with PRIMA (portable FWD)

Measuring with PRIMA is done as follows

### **2. Testing in the field**

Location 1

Location 2

Location 3

Location 4

Location 5

### **3. Measuring results**

Location 1

Location 2

Location 3

Location 4

Location 5

### **4. Conclusion**

### **5. Supplementary remarks**

### **6. References**

## **1. Introduction and background**

The degree of compaction has for many years been applied as a measure for, whether a required bearing capacity has been achieved.

The sand refill method as well as isotope equipment have been applied for the determination of compaction degrees.

Compaction control in connection with backfilling is difficult and must be done with great care.

Compaction control with isotope equipment requires a special education due to the radioactive source in the equipment.

A third method is the use of a portable falling weight deflectometer (FWD), a so-called mini FWD. Carl Bro Pavement Consultants (CBPC) has developed the PRIMA portable FWD in cooperation with the company KEROS. The development work was based on CBPC's ideas and experience within this field.

The above methods have the purpose of determining the degree of compaction, which gives an indirect expression of the achieved bearing capacity, as differences in the material used in the structure may, in comparison to the reference material, have a negative influence on the bearing capacity although the compactness of the material complies with the requirements.

The present report is an investigation of the utility of the PRIMA equipment.

### **Background:**

In the spring of 1998 CBPC needed a mini FWD for bearing capacity measurements/ compaction control on unbound materials. The development of the PRIMA FWD was based on our many years of experience with the production of traditional falling weight deflectometers.

The first prototype of the PRIMA portable FWD was ready in June 1998 and was presented at the BCRA conference in Trondheim. The equipment was met with great interest.

A project to compare the PRIMA equipment to other already accepted measuring methods was started. The methods chosen were static plate bearing testing and dynamic plate bearing testing using falling weight deflectometer (FWD).

## **1.1 Measuring equipment:**

In order to be able to evaluate the measuring results and to understand the conclusions made on the basis of these results, it is necessary to know, how the various kinds of equipment work and what they measure. The measuring equipment is thus introduced below:

## **1.2 Static plate bearing testing equipment:**

Equipment for static plate bearing testing consists of the following parts:

1. A moss rubber plate with a diameter determined for the test placed on top of the material/structure to be tested.
2. An aluminium plate with the same diameter put on top of the moss rubber plate in order to subject the structure to the required contact pressure.
3. A rectangular frame with a dial gauge. The frame is placed in the centre of the aluminium plate.
4. A reference beam of a length of approx. 4 m to hold a dial gauge
5. A dial gauge with a resolution of 2/1000 mm.
6. A measuring rod, which penetrates the holes drilled for the purpose in the moss rubber plate (1), the aluminium plate (2) and in the rectangular frame (3). This rod has a circular plate on the top where a dial gauge measures the up- and downward movement.
7. A plate with a diameter of 4 cm placed on the structure under the moss rubber plate. The measuring rod (5) rests on the top of this plate during the measurement.
8. On the surface of the rectangular frame (3) a hydraulic cylinder is placed and connected to a hydraulic pump. The pump is equipped with a manometer allowing the pressure to be read.
9. A lorry or a ditch digger acts as support load on the hydraulic cylinder.

### **1.2.1 Static plate bearing testing is done in the following ways:**

#### **1.2.2 The general method:**

- a. The measuring plate (7) is placed on the surface of the material to be measured.
- b. The moss rubber plate and the aluminium plate are placed on top of the measuring plate (a).

- c. The loading frame (3) with measuring rod (6) is placed on top of the measuring plate (a) and the moss rubber plate (b).
- d. The hydraulic cylinder (8) is placed on top of the frame.
- e. The lorry/ditch digger is placed so that the cylinder can press against a horizontal surface of the lorry/ditch digger.
- f. The reference beam (4) is set up with the dial gauge (5) placed so that there is contact to the measuring rod (6) and the dial gauge is in the centre of its measuring range.
- g. The hydraulic pump is pumping until there is contact to the support load.

### **1.2.3 The Danish method:**

- h. The dial gauge is read and noted.  $D_0$ .
- i. The pumping continues until the required pressure has been obtained, then a one-minute pause until the dial gauge is steady. If the pressure falls then the pumping is continued to maintain the pressure.
- j. The dial gauge is read and the result noted ( $D_1$ )
- k. The pressure is released and then a one-minute pause
- l. The dial gauge is read and the result noted ( $D_2$ ).
- m. Step **i** to **l** is repeated twice.
- n. The difference between the readings  $D_1$  and  $D_2$  is calculated for the three loading sequences and the average  $D_x$  is calculated.
- o. The surface E modulus is determined by means of the below equation:

$$E_0 = 1.5 \times \text{contact pressure} \times \text{plate radius} / D_x$$

### **1.2.4 The Swedish/German method:**

- h. The dial gauge is read and the result noted.  $D_0$ .
- i. The pumping continues until 1/5 of the required pressure is obtained, then a one-minute pause until the dial gauge is steady. If the pressure falls, the pumping is continued to maintain the pressure.
- j. The dial gauge is read and noted.  $D_{1,1}$
- k. The pumping continues until 2/5 of the required pressure is obtained, then a one-

minute pause until the dial gauge is steady. If the pressure falls, the pumping is continued to maintain the pressure.

- l. The gauge is read and the result noted.  $D_{1,2}$
- m. The process is continued by increasing the pressure by 1/5 until the maximum pressure has been obtained and the values  $D_{1,3}$ ,  $D_{1,4}$ , and  $D_{1,5}$  are noted.
- n. The pressure is released, then a one-minute pause.
- p. The dial gauge is read and the result noted.  $D_2$ .
- q. The difference between  $D_0$  and  $D_{1,5}$  ( $D_{x1}$ ) is calculated and  $Ev_1$  is calculated by means of below equation:  
$$Ev_1 = 1.5 \times \text{contact pressure} \times \text{plate radius} / D_{x1}$$
- r. The difference between  $D_2$  and  $D_{2,4}$  ( $D_{x2}$ ) is calculated and  $Ev_2$  is calculated by means of below equation:  
$$Ev_2 = 1.5 \times \text{contact pressure} \times \text{plate radius} / D_{x2}$$
- s. The ratio  $Ev_1 / Ev_2$  is determined and should be below 2.

### **1.3 Bearing capacity measurements with heavy FWD:**

1. A circular loading plate with a hole in the centre. Normally the radius of the plate is 30 cm and four-split.
2. On top of the plate a hollow cylinder is mounted, which transfers the impact load to the plate.
3. Inside the cylinder a seismic sensor is mounted which through a hole in the loading plate can measure the up and downward movements in the pavement.
4. At the top of the cylinder a load cell is mounted, which records the pressure on pavement surface.
5. The load cell and the seismic sensor are connected to a portable computer, which records the force and the deflection.
6. On top of the load cell the loading platform is placed.
7. On top of the loading platform a set of spring elements is mounted. Normally the spring elements are made of rubber.

8. On the loading platform a lifting system is mounted, which is used for hoisting the weights to a determined falling height from where a weight is dropped.
9. The loading platform with all other elements is mounted on a trailer, or built into a van allowing it to be lowered on to the pavement to be measured.
10. More seismic sensors can be mounted on the falling weight deflectometer allowing recording of the deflection of the pavement in various distances from the loading centre.

### **1.3.1 Measuring with FWD is done as follows:**

- a. The loading platform with all elements is lowered from the trailer/van until the loading plate with seismic sensor rests on the surface of the material to be measured.
- b. The weight is hoisted to the wished falling height and dropped on to the spring elements.
- c. The spring elements stop the fall whereby a force is transferred to the platform and down through the load cell to the loading plate where the material underneath the plate is impacted.
- d. The impaction is recorded via the seismic sensor and the electronics  $D_0$ .
- e. The load cell records the actual impact on the surface.  $K_0$
- f. The steps **b – e** are repeated 3 times.
- g. The values from  $D_0$  and  $K_0$  are stored in a data file for later analysis/calculation.
- h. The value  $E_0$  is determined by means of the below equation:

$$E_0 = 2 \times (1 - 0,5^2) \times \text{plate radius} \times \text{contact pressure} / \text{impaction}$$

### **1.4 Bearing capacity measuring with PRIMA 100 (portable FWD):**

PRIMA 100 is constructed in the following way:

1. A circular loading plate with a hole in the centre. Normally the diameter of the plate is 30 cm.
2. On top of the plate a hollow cylinder is mounted which transfers the load to the plate
3. Inside the cylinder a seismic measuring sensor, which through a hole in the loading plate is capable of measuring the up- and downward movements in the pavement.

3a. PRIMA 100 is available with 2 extra geophones for deflection measuring next to the loading plate. For the test dealt with in this paper, only one geophone was applied.

4. On top of the cylinder a load cell is mounted, which records the pressure from the pavement surface.
5. On top of the load cell is a loading platform.
6. On top of the loading platform a set of spring elements is mounted. Normally these elements are made of rubber.
7. On the loading platform a slide rod is mounted, which guides the weight, which is hoisted manually to a preset falling height from where it is dropped.
8. On the slide rod is a catch, which holds the weight until a measuring is to be performed.
9. The load cell and the seismic sensor are connected to a portable computer, which records impact and deflection.

#### **1.4.1 Measuring with PRIMA 100 is done as follows:**

- a. The equipment with all elements is placed on the surface to be measured.
- b. The weight is hoisted to the required height and is dropped down onto the spring elements.
- c. The spring elements stop the fall and an impact is transferred to the platform and down to the load cell and further on to the loading plate. The material underneath the plate is impacted.
- d. The impaction is recorded by the seismic sensor and the electronics  $D_0$ .
- e. The load cell records the actual impact on the surface  $K_0$ .
- f. The steps **b** – **e** is normally repeated 3 times.
- g. The values from  $D_0$  and  $K_0$  are stored in a data file for later analysis / calculation.
- h. The value  $E_0$  is determined by the following equation:

$$E_0 = 2 \times (1 - 0,5^2) \times \text{plate radius} \times \text{contact pressure} / \text{impaction}.$$

## **2. Testing in the field:**

In order to compare PRIMA 100 portable FWD (PRIMA) with other measuring methods comparative measurements were made on five different locations. All measurements were made on unbound base layer and the base layers differed from each other in strength and sub-structure. The individual locations are described below:

### **2.1 Location 1:**

A part section of the motorway to the Øresund Bridge near Lernakken south of Malmø, Sweden.

The measurements were made on top of a crushed stone base layer in accordance with a Swedish recipe.

Measurements were performed with FWD, static plate bearing testing equipment in accordance with the Swedish standard, and with PRIMA.

### **2.2 Location 2:**

A newly constructed road network near Øsby east of Haderslev, Denmark.

The pavement is base gravel II as per the standard set in the Danish Road Rules but only pre-compacted and therefore rather weak.

Static plate bearing testing and PRIMA were applied for the measurements.

### **2.3 Location 3:**

A newly constructed road network in Ribe, Denmark.

The pavement is base gravel II as per the standard set in the Danish Road Rules. This was fully compacted and had just been handed over to the client without remarks.

Static plate bearing testing equipment and PRIMA were applied for the measurements.

### **2.4 Location 4:**

A parking area for trucks in Vejen, Denmark.

The pavement consists of a gravel base layer as per the standard set in the Danish Road Rules. The pavement was rather compacted due to the traffic driving on it.

FWD and PRIMA were used for the measurements.

## 2.5 Location 5:

A side extension of the main road Varde-Holstebro near the town of Kvong, Denmark.

The pavement consists of a newly laid gravel base layer as per the standard set in the Danish Road Rules with more stringent requirements as to content of crushed aggregate.

FWD and PRIMA were applied for the measurements.

## 3. Measuring results:

### 3.1 Location 1:

The tested area consists of crushed base layer granite aggregate on a pressure distributing layer of granite crushed stone on top of a stabilised subgrade of clay.

The structure is designed for motorway traffic and should thus be considered extremely stable. High E moduli should therefore be expected. The measuring results should be evaluated separately as mechanic changes were made on the equipment after these measurements and before the other measurements.

Measuring site: Motorway near Malmö, Sweden

Surface: Crushed granite

Measuring point	Static $E_{v_2}$	PRIMA $E_0$
6	153	66.8
9	165	62.6
10	180	66.4
1	210	61.8
4	217	64.9
7	223	68.2
5	235	70.0
3	239	59.2
2	250	68.0
8	251	56.7

Measuring site: Motorway near Malmö, Sweden

Surface: Crushed granite

Measuring point	FWD $E_0$	PRIMA $E_0$
8	180	56.7
12	183	61.1
1	194	61.8
9	204	62.6

4	201	64.9
2	218	68.0
7	216	68.2
5	224	70.0

### 3.2 Location 2:

The tested area had a pavement consisting of a gravel base layer on top of a subbase layer. The subgrade is clay.

The gravel base layer has only been pre-compacted and had thus only obtained low values both with the method static plate bearing testing and with PRIMA. The two measuring points represented the extreme points in the measuring series.

Measuring site: Developed area in Øsby, Denmark

Surface: Base gravel

Measuring point	$E_0$ static Mpa	$E_0$ PRIMA MPa
70R	69	48.0
80L	91	54.5

Furthermore it should be mentioned that the measurements with static plate bearing testing were difficult to perform due to the low degree of compaction.

### 3.3 Location 3:

The pavement of the tested area consists of a gravel base layer on top of a subbase layer. The subgrade is sand. The gravel layer is fully compacted and thus it could be expected that the values obtained would be guiding values for what could be obtained provided that the compaction has been satisfactory made.

The nine measuring points represent a wide spectrum of the measuring values. However, the highest value should not be considered as representative for the relation between static plate bearing testing values and PRIMA values.

Measuring site: Newly laid road network in Ribe, Denmark

Surface: Base gravel

Measuring point	$E_0$ static Mpa	$E_0$ PRIMA MPa
2	120	75.0
6	129	70.5
8	133	102.0

3	136	96.0
1	140	115.0
7	150	132.5
5	156	109.0
9	169	153.0
4	274	159.0

### 3.4 Location 4:

The pavement of the tested area consists of a gravel base layer on top of a subbase layer. The subgrade is sand. The gravel base layer is fully compacted. It should then be expected that the obtained values would be guiding as to what could be obtained provided that the compaction has been satisfactorily made. Furthermore the pavement had not been subjected to traffic over a long period and the measurements are thus representative for the upper end of the measuring values.

Measuring site: Parking area for PLUS, Vejen, Denmark.

Surface: Base gravel

Measuring point	E <sub>0</sub> FWD MPa	E <sub>0</sub> PRIMA Mpa
1	293.5	132.3
2	288.4	139.2
3	276.1	131.9

### 3.5 Location 5:

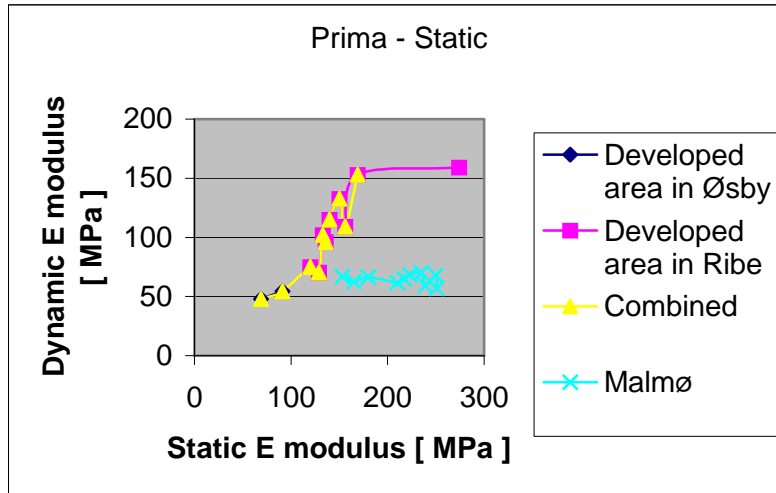
The pavement of the tested area consists of a gravel base layer on top of the subbase layer. The subgrade is sand. The gravel base layer is fully compacted and thus it should be expected that the obtained values are guiding for what could be obtained provided that the compaction is satisfactorily made. The six measuring points represent a wide spectrum of measuring values.

Measuring site: Main road north of Varde, Denmark

Surface: Base gravel

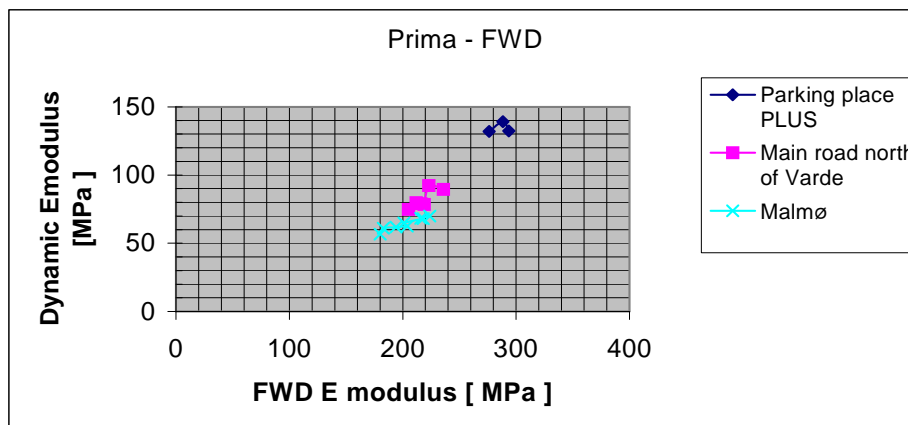
Measuring point	E <sub>0</sub> FWD MPa	E <sub>0</sub> PRIMA Mpa
3	205	75.0
5	212	79.9
6	216	79.0
4	219	78.6
2	223	92.4
1	236	89.6

Below a graphic presentation of the locations 1 to 3 shows the static plate bearing testing and PRIMA measurements.



The curve indicates that there is a trend between the static plate loading value and the PRIMA value for the two Danish locations measured in 1999, whereas no trend can be found from the measurements performed in Malmø in 1998.

Below the relation between measurements with FWD and PRIMA are shown for the location in Malmø and the two Danish locations, where this kind of comparison was made.



The curves demonstrate that there is a trend for the individual locations as well as for the entire set of measurements. It should however be noted that a mechanic modification has been made to the PRIMA equipment between the measurements in

Malmø and the measurements on the two other locations. The result of this seems to be positive as a trend can be seen from the last measurements.

The modification to the PRIMA equipment is a hole in the loading plate allowing the equipment to measure the pavement surface deflection directly on top of the surface, where as the first versions of the equipment measured on top of the loading plate.

Apart from this modification, the cable connections and the filtering of signals have been modified.

#### **4 Conclusion:**

In spite of the very low amount of measuring data at our disposal, a clear relation seems to exist between E moduli measured by means of static plate loading and by means of PRIMA FWD within the range of  $E_0 \text{ PRIMA} = 1.3 \times E_0 \text{ static} - 70$ .

The measuring results also show a relation between E moduli measured by FWD and PRIMA FWD.

The material present is however not sufficient to decide, whether the relations vary in accordance with the subsoil conditions and type of material in the pavement structure.

The differences between the  $E_0$  values measured by the various equipment types can be taken to be due to the difference in loading size and type. PRIMA works with a far lower contact pressure compared to the two other methods, whereas the static plate bearing testing subjects the pavement to load very slowly and thus obtains a larger depth impact than the two dynamic equipment types.

In order to find out, a far larger amount of measurements should be made with all three types of equipment.

#### **5 Supplementary remarks:**

As regards further measurements for comparison, two projects are planned for year 2001, where static plate bearing testing is to be performed. This data should be used in order to have a larger static basis for evaluation.

#### **6 References:**

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