NATURAL BUILDING STONE:
FIELD METHOD FOR MEASUREMENT OF BOWING OF CLADDING PANELS

Key words: Natural Stone, Marble, Façade elements, Cladding panels, Building, Bowing, Deterioration, Dimensional stability.

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1 SCOPE

This NORDTEST method specifies a methodology and a measuring device (the ”Bow- meter”) for carrying out field measurement of dimensional changes and deformation of natural stone panels used as exterior cladding [1]. The method represents a tool for the inspection and assessment of status and prediction of further development on existing facades where damage in the form of bowing of natural stone panels have been observed. This phenomenon is experienced occasionally for crystalline marble [2] when used as exterior cladding.

Risk analysis, together with the purpose of each specific inspection and assessment and the accessibility of suitable measurable panels will control and influence the extent of the field measurements.

The method does not deal with the causes for bowing or other kinds of changes in the cladding material, but is does give some guidance on the evaluation of the results. Further laboratory analysis [1] of panels dismounted from the facade may be essential, in order to evaluate if the bowing indicates e.g. strength loss in the material. When possible the laboratory analysis should also include measurements on unexposed (spare) panels.

The methodology is illustrated in Annex A for an Introductory Assessment level. In addition, some suggestions for how the results may be discussed in order to give recommendations for further actions are given.

2 FIELD OF APPLICATION

The method is suitable for façade assessment at various inspection levels, and the objective of the field investigation may be to:

- Get an general overview of the state of the cladding or material (Introductory Assessment)
- Perform a detailed and thorough inspection of a selected set of panels (Detailed Assessment)
- Follow-up investigations of selected panels or façade areas to investigate and predict changes over time (Follow-up Assessment).

Even though directed towards assessment of damages in exterior stone claddings, both the methodology and the test equipment may be used for measurements of all kinds of bowing or irregularities in cladding or paving elements of natural stone as well as other materials.

3 REFERENCES

[1] Schouenborg, B., Grelk, B., Brundin, J-A. & Alnæs, L., ”Final Report from NORDTEST project No 1443-99 ” Buktningsprovning av marmor för fasadbeklädnad (Bowtest for stone cladding panels of marble).
[2] prEN 12670 - *”Terminology of Natural Stone”*
[3] prEN 12440 - *”Denomination of Natural Stone”*
[4] prEN 13373 – *“Natural stone test methods – Determination of geometric characteristics on units”*

4 DEFINITIONS

Bowing: In this test method, bowing is used as a term for a panel that has changed from an originally flat and plane shape to a curved or dished shape in a concave or convex direction. Other terms commonly used for the same phenomenon are warping and dishing.

Concave: centre part of the panel is bowing inwards (towards the building structure).

Convex: centre part of the panel is bowing outwards (away from the building structure).

Dowel hole: Drilled hole, usually at the edge of the panel, expected to receive a dowel of an anchoring device.

Measuring point: the location on the panel where measurement is performed.

Panel: natural stone unit (slab) used as exterior cladding on a building/project.

Support points: The locations on the panel on which the supporting legs of the test equipment are placed during the measurement.

5 METHOD OF TESTS

5.1 Project description

Information important for the inspection and further assessment should be collected for each relevant building/project. See also Annex B. At least the following information should be documented:

- Building type and dimensions (size, dimensional proportions, location, surroundings, etc.).
- Involved parties (Building proprietor and present administrator/owner, building contractor, natural stone contractor/supplier).
- Building documents: design and construction specifics (framework system, facade system, insulation/ventilation conditions, and material usage).
- Facade design and construction of the natural stone cladding (distribution, type and widths of joints, panel dimensions, anchoring/fixing system) according to the construction documents.
- Natural stone material: trade name, petrographical name, quarry location.
- Year of construction and any documented rebuilding and maintenance/repair work.
- Documentations in the form of e.g photos etc. for the actual building.

5.2 Selection of inspection level and measuring localities

5.2.1 General

Depending on the purpose of the investigations, the project may be divided into logical sections. Each section shall be further identified (e.g. facade facing SSW, uninterrupted cladding of four floors) and described (i.e. number of panels per facade section and code marking of the panels in a x-y co-ordinate system). Preferably use available plan and elevation drawings for this classification purpose.

5.2.2 Introductory Assessment

This assessment level should be understood as an ocular inspection. Panels that are to be included in the measuring area are selected subjectively with regard to accessibility, observed or anticipated variations regarding damages, construction specifics, panel dimensions etc. The selection criteria are to be noted.

5.2.3 Detailed Assessment

The number and locality of the panels to be measured within each identified section can be chosen at random or be based on a subjective selection of measuring sites. A minimum of one panel per each principal part of the building shall be chosen, e.g. point of the compass, corners, high up on the building, at ground level, in the middle of a façade, under windows i.e. representing different micro-climatic conditions concerning temperature and moisture. Drawings and/or descriptions of the selected measuring areas shall be documented. For the selected panels, the following measurements shall be performed see figure 1:

- For all panels, measure the midpoint (MC) between the two diagonals (C1-C4 and C2-C3)
- For ≥ 10 % of the panels, measure the midpoint (ML, MR, MU, MD) and points of the dowel holes (if the positions are known; D1-D4/d1-d4) along the edges (C1-C3 and C2-C4 / C1-C2 and C3-C4) and in addition the midpoints (MC) along the centrelines
- (ML-MR and MU-MD).
- For ≥ 5 % of the panels, make measurements at regular intervals along the edges (C1-C3 and C2-C4 or C1-C2 and C3-C4) and centrelines (ML-MR and MU-MD).

5.2.4 Follow-up Assessment

In order to investigate and predict the development of the stone performance over time, a follow-up assessment is performed at chosen intervals on selected or all of the panels included in the Detailed Assessment (5.2.3). Repeated measurements over time may call for an exact and durable labelling of the measuring points on each panel, if there of any reason is chosen another measuring point than 40 mm from the panel edge, as suggested in figure 2. The measuring intervals are to be determined from case to case, depending on the damage situation, the speed of bowing in the past and the need for monitoring.

5.3 Test equipment

5.3.1 Equipment for measurement of bowing

For the Introductory Assessment, measuring devices such as i.e. spirit level, straight-edge or a rule is sufficient, cf. for instance [4]. For the Detailed and Follow-up Assessment, a specially designed test equipment that offers the required flexibility and accuracy shall be used. A prototype instrument, the “Bow-meter”, offers these essential requirements, and consists of the following parts, see figure 2:

- A stiff straight-edge made of a form-stable aluminium U-section or equivalent for zero-setting purposes,
- A stiff, box shaped aluminium section, the actual measuring bridge,
- A rule (mm-graduated) fixed lengthways on the measuring bridge,
- Two supporting-leg mounts – one with two, the other with one supporting leg,
- One mount for a digital vernier calliper,
- A digital vernier calliper with zero-setting function and graduated 0.01 mm working.

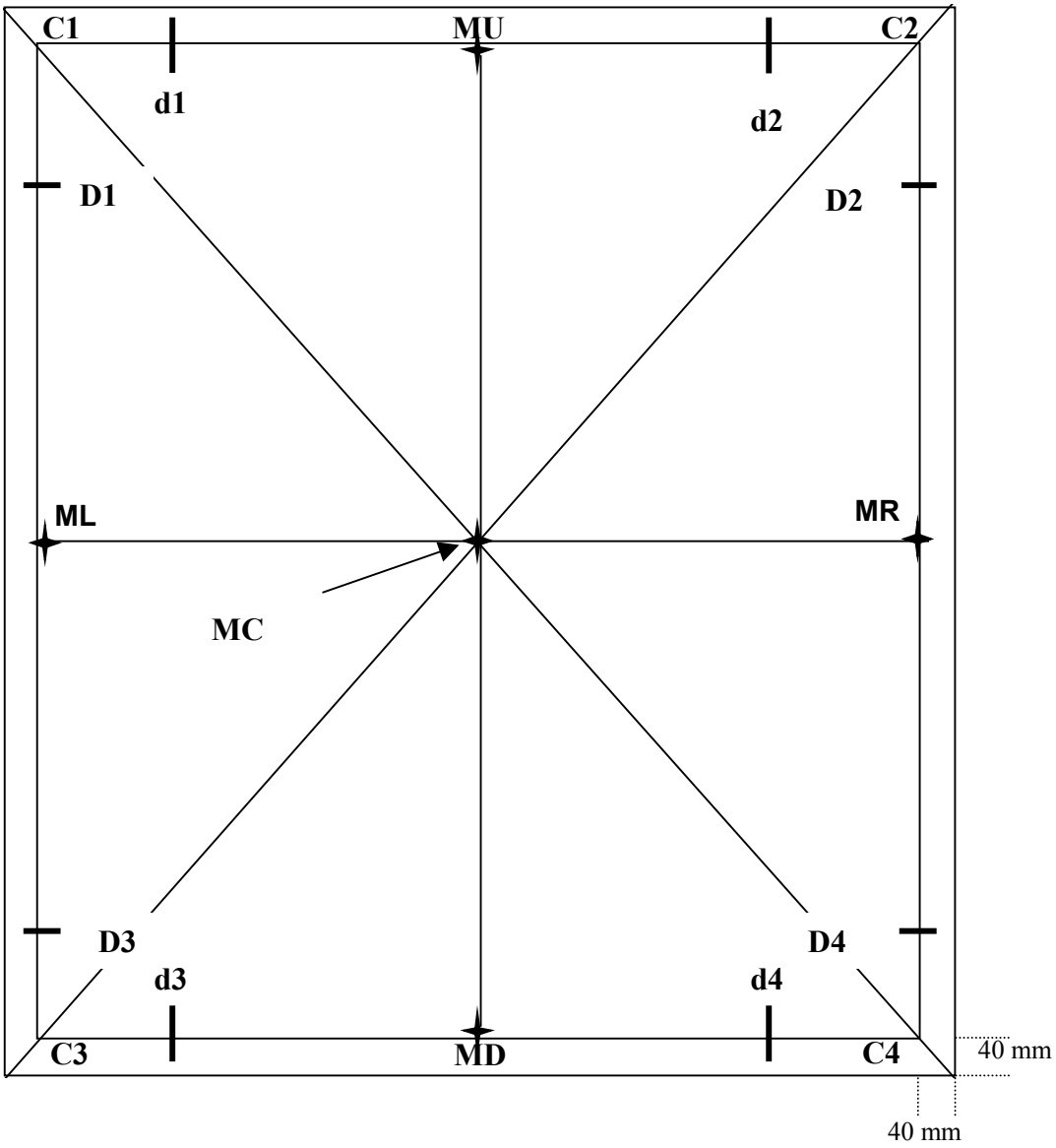


Figure 1. *Sketch showing the division of a panel into different measuring lines and points.*

5.3.2 Other relevant field equipment

For façade assessment in general and evaluation of stone performance in special, some additional equipment may be of help, for example:

- Compass
- Folding rule or similar, slide calliper
- "Covermeter" – metal detector to locate anchoring
- Permanent marker
- Thermometer
- Camera
- Equipment for measuring the surface temperature of the panel.

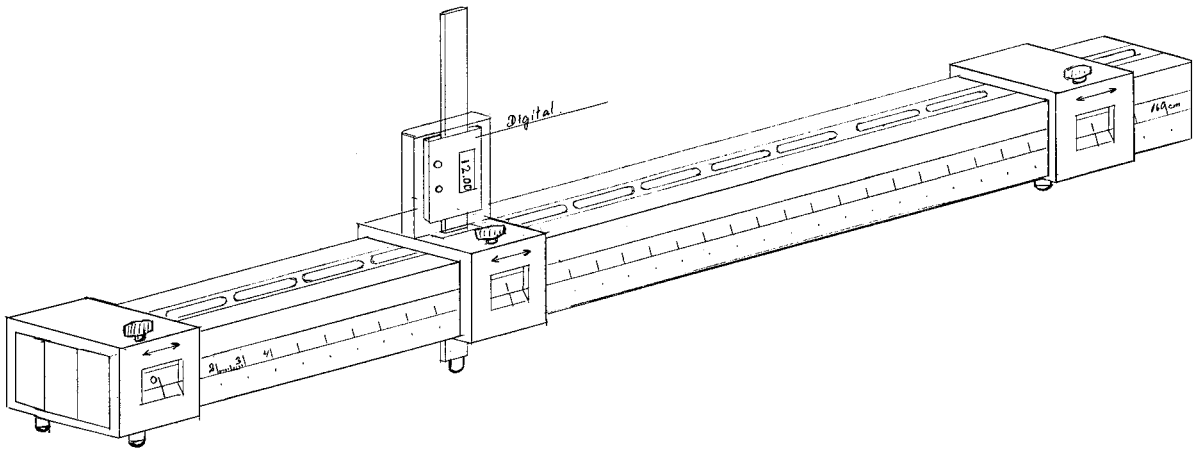


Figure 2. *Sketch of the Bow-meter.*

5.4 Precision

The reproducibility (R) when using the Bow-meter has been determined during a field inspection performed by 6 persons, as 6 times 8 different "mid-point" readings on the same panel.
R is less than 0,2 mm.

5.5 Procedure

5.5.1 Introductory Assessment

No requirements are specified on the actual measuring area or the measuring procedure. Using a spirit level or straight edge, rule, etc. is expected to be sufficient, but more accurate test equipment like the Bow-meter may also be applied. The procedures or part of the procedures described in the following sections may as well be chosen for this preliminary investigation. See annex A for an example.

5.5.2 Detailed Assessment

For the measurement on each selected panel, the following procedure shall be followed:

1. Fix one supporting leg mount over the zero-point of the ruler
2. Fix the other supporting leg mount at a distance corresponding to the distance between the intended supporting points
3. Fix the mount for the vernier calliper in a position corresponding to the intended measuring point, i.e. the midpoint.
4. Letter the facade panels that shall be measured on a drawing or sketch, and measure and record the height and width of each panel; see Annex C for a suggested registration form.

5. Mark the locality for the supporting points (permanent) on each panel
6. Zero-set the vernier calliper against the straight-edge
7. Place the supporting leg (with two legs) at the zero point of the rule over the supporting point lying on either of the two co-ordinate axes, e.g., E1=Origin, E2, E3, MD. Record which supporting part of the bow-meter that is placed over which point on the panel in order to be able to do the exact same measurement in the future.
8. Place the other supporting leg over the other intended supporting point
9. Press the vernier calliper onto the panel and read and record the value. Be careful not to put any pressure on the bow-meter other that over the supporting legs.
10. Move the vernier calliper to the next measuring position with identical size conditions – repeat the procedure from item 8 for all measuring positions with identical measuring conditions
11. Adjust the other supporting leg mount and/or the vernier calliper mount to a new position for the next measuring position
12. Repeat the procedure from item 7-11.

Note: Remember always to set the vernier calliper in zero position whenever changes are being made in measuring distance and/or position for the dial indicator.
If the bow-meter has been calibrated on a plane surface in the laboratory it may be possible to leave out the zero-set between measurements on different panels.
It is important to perform the measurements consistently and therefore orient the Bow-meter similar on each panel and on every occasion of measurement.

5.5.3 Follow-up Assessment

The measuring procedure is the same as described in 5.4.2. Remember to check the code marking of facade panels from 5.4.2 on drawing or sketches, to check the length and height of the panels, and to check the marking of the supporting points (permanent) or re-measure the facade panel(s) of the measuring area.

5.6 Expression of results

The measuring result is presented as:

$B = (d / L) * 1000$

Where

B	Bowing expressed in [mm/m], to the second decimal
d	Measuring value in [mm], to the second decimal Positive values represent concave bowing Negative values represent convex bowing
L	measuring distance in [mm]

Present individual measuring values and calculate the mean and the standard deviation. The results can be given in a form as shown in Annex A or Annex C. The maximum value for each section is always reported.

5.7 Report

The report shall include at least the following information, when relevant:

a) Identification number of the test report.
b) Name and address of the organisation or the person who ordered the test.
c) Name and address of the organisation and person(s) that performed the test.
d) Project description.
e) The method for selection of façade sections and measuring areas and panels to measure.
f) The purpose of the field measurements.
g) Identification of the measurement procedure, test equipment and any other instruments used.
h) Date and time (start and end) for the field investigation.
i) Weather conditions at the time of measurements (temperature, rainfall etc.) and surface temperature of the measured panels for the detailed and follow-up assessments.
j) Inform whether the field measuring is supplemented with any laboratory tests.
k) Any deviation from the test method together with other information of importance for judging the result.
l) Test results as described under each assessment type.
m) Date and signature.

ANNEX A. Templates for presentation of data and for assessment

A.1 Proposal for template for recording observed bowing

The example is fictious.

Project /Façade Section	**Points of the Compass**	**Façade type**	**Characterisation of the investigation site**	**Bowing tendency (visual assessment)** *0 = No bowing* *1= Signs of bowing* *2= Clear bowing* *3= Severe bowing*	**Photo ref. number**
A–B	North	brick	Not applicable	Not applicable	1; 3
B–C	West	Type 2	Upper part	concave / 3	2; 4; 5; 23
			Lower part	concave / 1–2	2
C–D	North	Type 2	Upper part	concave / 2–3	2
D–E	West	Type 1	Upper part – facade panels	concave / 3	6; 7; 8
			Upper part – ornamental friezes	convex / 1	6; 7; 8
E–F	North	Type 1	Upper part – facade panels	concave/convex / 1	1; 9
			Upper part – ornamental friezes	convex / 2	9
D–G–J	North / East	Type 2	Drawn in part under roof	0	1; 20
F–H–I-K	East	Type 1	facade panels	0	10; 14; 20; 21
			ornamental friezes	convex / 1–2	10; 14; 20;
J–Q	East	glass	Partly under roof	Not applicable	21; 22
K–...–R	East	Type 1	Street level	0	21; 22; 11
Q–S	North	Type 2	Parapets	0	12; 22
			Cladding to base	collision damage	15
S–T	West	Type 2	1 floor height about 4m	concave / 1	13; 16
U–V	West	Type 2	Rows over glass section	concave / 1	13
V–W	North	Type 2	Rows over glass section	concave / 2	13; 17
W–X	East	Type 2	1 floor height about 4 m	concave / 3	18; 19
X–Y	South	Type 2	1 floor height about 4 m (but in “shade”)	concave / 2	---
Y–Z–AX	East/ North	brick	Not applicable	Not applicable	---
AX–BX–CX	East	Type 3	Frieze over window	convex / 1	---
CX–DX	South	Type 3	Frieze over window	concave / 1	25
BX–EX–GX	South	Type 3	Frieze over window	concave / 1	25
FX–HX–IX	South		Brick in entrance section	Not applicable	25

A.2 EXPRESSION OF RESULTS

In the following tables, examples on how the results may be expressed are given for the various modes of measurements.

Table A.1 Measurements of the midpoint between diagonals.

Support point No.1	**Support point No. 2**	**Locality for Measuring point**	**Measuring distance (mm)** [L]	**Measured value (mm)** [d]	**Bowing (mm/m)** B=(d/L)*1000
E1 (Edge 1)	E4 (Edge 4)	MC	999	37.00	37.04
E2 (Edge 2)	E3 (Edge 3)	MC	999	32.00	32.03

Measurement of the midpoints along edges and centre lines and measurements at points for dowel holes are reported in the same way.

A.3 EVALUATION AND DISCUSSION

In addition to the information requested for the test report (see 5.6), the following information and evaluations are of importance for the discussion of possible repair or monitoring actions:

- If laboratory analysis of strength loss is performed, this can be compared with the bowing tendencies in a time versus strength diagram.
- Compare the strength loss with the originally dimensioning requirements on strength in cases where such data is available, and draw conclusions regarding permanent change in size from day one to today.
- Give recommendations regarding the need to exchange panels to determine strength by laboratory tests.
- Give recommendations regarding the need of complementary laboratory tests and the need for follow-up assessment.

ANNEX B. Example of inspection form, useful for project description

This form may be used for documentation of information about the project/facade where field measurements are planned.

Locality

Project name	
Country	
City/Place	
Street address	
Point of CONTACT	

Review Information

Reporter	
Date of Visit	
Other present	
Key Words and comments	

Project specifics

Type of Project	
Construction Year	
Owner	
Architect	
General Contractor	
Stone Contractor	
Stone Supplier	
Building size	
Stone Facades	
Structure	
Climate characteristics	

Stone and Cladding Information

Type of Stone	
Type of Stone – other	
Design characteristics	
Sizes of façade panels	
Thickness of panels	
Anchoring system	
Joints wide and type of sealant	
Other	

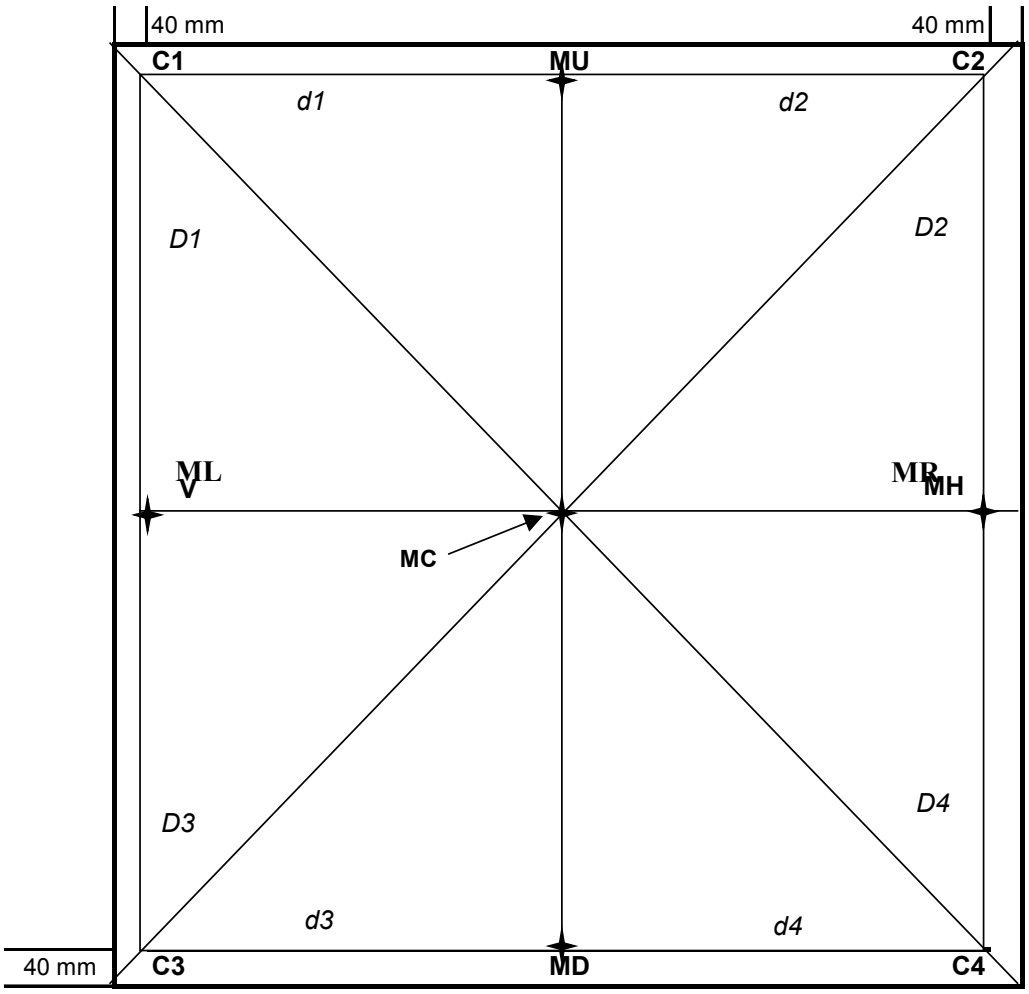
Stone performance

Problems Yes/No	
What problems (Describe)	
Original surface treatment of stone	
Today's stone surface	
Other Observations Cracks, discoloration etc	
Any actions taken to repair or control before	
Owners comments to status of facade cladding	
Type of contacts with Owner	

Weather and building climate information

Nearest Weather Station	
Other weather registrations available ?	
Information about building heating, air conditioning available ?	

ANNEX C. Example of Excel form to be used for each panel to be measured



Weather conditions during measurements:

Supporting points	Measured value	Measuring points
D1-D4		MC
C2-C3		MC
C1-C2		MU
ML - MR		MC
C3-C4		MD
C1-C3		ML
MU - MD		MC
C2-C4		MR

Hour:

Surface temp. of the panel:

Note: Remember always to set the Bow-meter in zero position when a change in measuring distance or the position for the vernier calliper has been changed

Note: It is advised to perform measurements at two different hours during the day, in order to study temp./humidity influences

Measure also at the fixing points, still with the Bow-meter's Supporting points in the corners

D1 or d1	
D2 or d2	
D3 or d3	
D4 or d4	

Slab Id:

Slab dimensions (mm):
(length (hor.) x height (vert.) x thickness)

Date:

Signature: