Effects of surrounding buildings on wind pressure distributions and ventilation losses for single-family houses

Part 2: 2-storey terrace houses

Bengt G. Wirén

The National Swedish Institute for Building Research

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SUMMARY

This report describes a wind tunnel investigation of wind pressure distributions over a 1:100 scale model of a row of five 2-storey, flat-roofed terrace houses. Measurements were made with the instrumented model either fully exposed to wind from all directions or surrounded by identical rows of houses in various regular arrays. Time mean pressures were measured at 300 locations on the model walls in a simulated turbulent wind. The wind angle was varied between 0^o and 90^o in increments of 15^o.

Pressure coefficients obtained from the tests were used for the calculation of air change rates and associated heat losses from a naturally ventilated full-scale house for a range of wind speeds, u, and internal-external temperature differences, ΔT. In these calculations the air leaks were assumed to be uniformly distributed over the building envelope. The leakage area was chosen to give, for an end unit of a wind-exposed row of houses, an air change rate of 0.45 1/h at u = 3 m/s and $\Delta T = 20^oC$, which approximately corresponds to the minimum requirement as stipulated in the Swedish building regulations.

Surrounding buildings affect both the magnitude and the distribution of wind pressures over the test house. The resulting change, ΔQ, in the ventilation loss, normalized with the loss, Q_e, from the test house in a wind-exposed position, is used to characterize the various building arrays with respect to their sheltering effect on the test house. For a given wind direction this ratio, $r_Q = \Delta Q/Q_e$, is shown to be a function only of a densimetric Froude number based on wind speed and internal-external temperature difference. The r_Q-value can be considered to be independent of the airtightness of the house.

The maximum reduction of heat loss, corresponding to $r_Q \approx 0.7$, was obtained for the centre unit in a row of houses located downwind of another row at a distance of 2 l (l = length of house unit).

Only a limited amount of the data obtained from the tests is presented in the report. The complete test results are available on request.

SYNOPSIS

In residential buildings with natural, i.e. weather-induced ventilation the ventilation rate may be higher than needed to ensure safe levels of indoor air quality. In cold and temperate zones the heat loss associated with excessive air infiltration may constitute an important part of the heat load on the building.

For the calculation of ventilation losses to be reliable, an accurate knowledge of the wind pressures acting on the building surfaces is required. However, most of the available wind pressure data refers to isolated buildings, fully exposed to wind from all directions. This situation is rarely encountered in practice.

In the present wind tunnel investigation the effects of surrounding buildings on the wind pressure distribution over a row of five 2-storey terrace houses have been studied. Pressure coefficients obtained in the tests have been used for the calculation of air change rates and associated heat losses from each of the house units for a range of winds speeds, u, and internal-external temperature differences, ΔT. In these calculations the leakage openings have been assumed to be uniformly distributed over the building walls.

The reduction of heat loss from a house due to the wind shelter offered by a certain array of surrounding houses varies with u, ΔT and wind direction. For a given wind direction this reduction, expressed in non-dimensional form as a reduction coefficient r_Q, is shown to be a function only of a densimetric Froude number based on u and ΔT. The r_Q-value is practically independent of the airtightness of the house.

When combined with local wind statistics the r_Q-values may be used by the planner to minimize wind-related energy losses by discriminating between alternative site plans.

FOREWORD

The aim of the present work is:

(i) to provide wind pressure data that are more realistic than those presently available for the calculation of wind-induced ventilation rates and associated heat losses from two-storey terrace houses, as influenced by adjacent, identical houses and

(ii) to illustrate, quantitatively, the influence of density and layout pattern of a group of houses on the ventilation loss from each house.

The work is part of the research program of the National Swedish Institute for Building Research. It supplements a similar study of wind pressure distributions over detached single-family houses that is described in an earlier report in this series /1/.

The assistance rendered by Lars Hedlund and Leif Claesson in carrying out the wind tunnel measurements is gratefully acknowledged. Thanks are also due to Margot Lööf for typing the manuscript and to Folke Glaas for preparing the figures.

Gävle, Sweden, February 1987.

Bengt Wirén

NOTATION

A	area of building envelope	m^2
A_l	area of leakage openings	m^2
a,b	distances between buildings, see Fig 3	m
c_p	1) local pressure coefficient, $c_p = (p-p_o)/q_o$ 2) specific heat of air	- kJ/kg K
Fr	densimetric Froude number, $Fr = u_o^2 T_i / gh\, \Delta T$	-
g	acceleration due to gravity	m/s^2
h	height of test house, reference height (full scale) for Froude number	m
l	length of test house	m
n	air change rate	1/h
p	local static pressure (time-mean) on building surface	Pa
p_o	static free stream pressure	Pa
Q	heat loss due to natural ventilation (subscripts e and s denote exposed and sheltered positions of the test house, respectively)	kWh/day
ΔQ	reduction of heat loss, $\Delta Q = Q_e - Q_s$	kWh/day
q	rate of volume flow	m^3/s
q_o	dynamic free stream pressure at roof-top level, $q_o = \rho u_o^2/2$	Pa
r_Q	heat-loss reduction factor, $r_Q = \Delta Q/Q_e$ (subscript m denotes conditions at Fr = 25)	-
T	air temperature (subscripts e and i denote external and internal conditions, respectively)	K
ΔT	temperature difference, $\Delta T = T_e - T_i$	K
u_o	mean wind velocity at roof-top level	m/s
V	internal volume of test house	m^3
α	area ratio, $= A_l/A$	-
β	wind angle, defined in Fig 3	degrees
ρ	density of air	kg/m^3

1. INTRODUCTION

Pressure differences acting across the building envelope due to wind and internal-external temperature differences drive air through cracks and interstices in the building surfaces, which results in an uncontrolled transport of heat from the building. The ventilation rate is often considerably higher than needed to ensure safe levels of indoor air quality and the associated heat loss may constitute, in cold or temperate zones, an important part of the total heat load on residential buildings with natural ventilation. Even in buildings with a nominally balanced mechanical ventilation system the weather-dependent pressures can give rise to excessive ventilation rates.

As energy conservation has become increasingly important, a variety of calculation models have been developed for predicting air change rates and heat losses due to natural ventilation. For these calculations to be realistic, an accurate knowledge of the wind pressures acting on the building surfaces is required. Most of the wind pressure data available at present, however, refer to isolated buildings fully exposed to wind from all directions, which is a situation rarely encountered in practice. Most buildings are, to some extent, sheltered from the wind by other buildings, vegetation belts or topography, which may cause substantial changes in both the magnitude and the distribution of wind pressure over the building surfaces. A calculation of ventilation losses that is based on pressure data for an isolated building will then yield unrealistic results.

Previous studies in this field have mainly concerned the effect on air infiltration of vegetation belts and fences, either in full scale, /2/, /3/, or in model scale in a wind tunnel, /4/, /5/, /6/. The effect of a group of surrounding buildings has been studied in wind tunnel tests in which the buildings - in various regular arrays - were simulated either by cuboids, /7/, or by rectangular blocks with varied frontal and side aspectratios, /8/. The influence of one or two upwind buildings has been determined in a series of wind tunnel experiments with model buildings of various form /9/. In all these tests wind pressures were measured only on the centre line of the model walls and for one wind direction, normal to the front face of the model (in the case of /8/ also normal to the side face). Associated heat losses were not calculated.

The influence of the spacing between simplified building models on both the wind forces on a downwind building and the characteristics of the wind flow between the models is described in /10/.

The work mentioned above has contributed to a general understanding of windbreak effects but there is still need for detailed information about the magnitude and distribution of wind pressures over buildings of certain forms, as influenced by adjacent buildings at different wind directions, to enable accurate predictions of wind-induced air infiltration to be made.

The purpose of the present wind tunnel study is to provide wind pressure data for a row of 2-storey terrace houses which is part of a group of identical house rows. Although the patterns of the building groups are schematic, they are typical of site plans in many recently developed areas.

The wind pressures obtained in the tests have been used as input data in an analytical model for the calculation of air change rates and associated heat losses from the house for a range of wind speeds and internal-external temperature differences.

2. EXPERIMENTAL FACILITIES AND PROCEDURE

2.1 Wind tunnel

The wind tunnel used for the investigation is of the closed-circuit type with a test section 3 m wide, 1.5 m high and 11 m long and a maximum wind speed of 23 m/s. The models were mounted on a 2.8 m diameter turntable, the centre of which is located 8.5 m downstream of the entrance of the test section.

2.2 Simulation of the natural wind

The atmospheric boundary layer over flat open terrain was simulated by means of spires at the upstream end of the test section and a 7 m fetch of 40 mm and 70 mm cubes in a regular array with a density of 10%, see Fig 1. The characteristics of the model boundary layer are given in /1/.

2.3 Building models

The building models were 1:100 scale, schematic models of rows of five 2-storey, flat-roofed terrace houses with dimensions as shown in Fig 2. The instrumented model was made of 3 mm plexiglass with 300 pressure taps of 0.5 mm diameter distributed over the walls, while the other models, identical in form, were made of solid wood. To facilitate the calculation of wind-induced air infiltration the locations of the pressure taps were chosen so that the measured wind pressures could be taken to represent averages over equal-sized areas in each one of the model walls.

2.4 Instrumentation and test procedures

The model surface pressures were measured using a pressure scanning switch fitted with a differential pressure transducer. The data acquisition system is described in detail in /1/.

The time-mean pressures were determined by averaging instantaneous pressure values sampled with a frequency of 10 Hz over a period of 15 seconds.

All tests were conducted at the maximum tunnel wind speed, which gave a wind speed of approximately 12 m/s at model roof-top level. The dynamic pressure at that level, used as reference pressure for the pressure coefficients, was measured at the location of the instrumented model - without the model present - and calibrated against the dynamic free-stream pressure measured by a fixed pilot-static tube located 1.25 m above the centre of the turntable. This tube was also used for the measurement of the static (reference) free-stream pressure.

The pressure data have not been corrected for tunnel blockage, which did not exceed 4%.

3. TEST PROGRAM

The model configurations investigated are shown in Fig 3. In the first series of tests the influence of one or two adjacent buildings was studied, these buildings being either located upwind of the test building or aligned with it, ('building' is here taken to designate a row of five house units). The spacing between the buildings was varied between 1 and 6 1, where 1 is the length of one house unit.

In the second test series the instrumented model was located at the centre of regular arrays of identical models spaced 1 or 2 1 apart. In these test series the wind angle was varied between 0^o and 90^o in increments of 15^o.

Finally some tests were carried out to enable an estimate to be made of the influence of adjacent buildings on the wind pressures over a building located at the edge of an array. These tests were made at wind angles $\beta = -45^o$, 0^o and 45^o.

4. AIR INFILTRATION MODEL AND CALCULATION PROGRAM

The numerical model used for the calculation of air change rates and associated heat losses is schematically described in /12/. The calculations were based on the following assumptions:

- The air leaks are uniformly distributed over the walls of the building while the roof is assumed to be airtight. These are no vents or other discrete openings in the building envelope.

- The leakage area corresponds to an air change rate n = 0.45 1/h for the end unit in an isolated row of houses at $\beta = 0^o$, u_o = 3 m/s and $\Delta T = 20^oC$.

- The leakage function has the form $q = const \cdot (\Delta p)^{0.5}$. The reasons for choosing 0.5 for the exponent are given in /1/.

- The internal flow resistance in each house unit is neglected.

- The living space volume of each house unit is 375 m^3.

For the calculations it has further been assumed that the mean rate of air flow trough the leaks is determined by mean-pressure differences across the building envelope; this assumption is implied in the chosen leakage function, which applies only to steady flow. Effects of turbulence in the external flow are thus neglected, which can be a significant source of error in the calculation of air change rates, /13/, /14/. The simplification may, however, be justified in the present work where the main purpose is to determine not absolute values of the air infiltration rate but relative changes in this rate as caused by adjacent buildings. The effects of turbulence on air infiltration can be considered to be approximately of the same magnitude in the two cases of wind exposed and sheltered house and they will therefore cancel out.

For all model configurations investigated air change rates and associated heat losses, Q, given by

$$Q = 6.7 \cdot 10^{-3} \cdot n \cdot V \cdot \rho \cdot c_p \cdot \Delta T \quad \text{(kWh/day)},$$

were calculated for wind speeds $0.5 \leq u_o \leq 8$ m/s and temperature differences $5 \leq \Delta T \leq 35^oC$.

The reduction of heat loss due to adjacent buildings has also been calculated as

$$\Delta Q = Q_e - Q_s$$

Expressed in an non-dimensional form as

$$r_Q = \frac{\Delta Q}{Q_e},$$

the heat-loss reduction is a function of the densimetric Froude number

$$Fr = \frac{u_o^2 \cdot T_i}{g \cdot H \cdot \Delta T}$$

as shown in /1/.

5. RESULTS AND DISCUSSION

5.1 Wind pressure measurements

5.1.1 Introduction

The external pressure coefficients presently used in Sweden for the prediction of air infiltration rates are those given in the Swedish National Building Code, SBN 80, see Fig 4a. Being intended for use in the structural design of a building they represent a simplified load distribution over a wind-exposed house at the wind direction most critical from the point of view of wind loading. They are therefore inadequate for the calculation of ventilation rates, for which more detailed information about the wind pressure distribution and its dependence on the wind direction and the degree of wind exposure is required. The purpose of the present study is to provide such information for two-storey block-type buildings.

The large amount of pressure data obtained from the measurements is exemplified in this report by diagrams showing horizontal c_p-distributions over the walls of the test house for different wind directions. For an isolated building, which is taken as the reference case, c_p-distributions are presented for five or three horizontal levels (at $\beta = 0^o$ and $\beta \neq 0^o$, respectively), while for the other building configurations c_p-distributions are given for only one level, namely at half the height of the building.

5.1.2 Discussion of results

The c_p-distributions over an isolated building are shown in Fig 4. The pressure is nearly constant with height over all faces of the building at $0 \lesssim \beta \lesssim 15^0$ and $75^0 \lesssim \beta \lesssim 90^0$. At intermediate wind angles the pressure on the windward long face decreases markedly toward the upper edge, while on the leeward long face a pressure minimum occurs halfway up the building. On the leeward short face the pressure is practically constant with height at all wind angles.

The effect of adjacent buildings is, in most cases, to radically change both the magnitude and the distribution of wind pressure over the building walls. With only one building located upstream of the test building this effect is limited to the windward long face at $0^0 \lesssim \beta \lesssim 30^0$, Fig 5 a. The separated flow over the leeward faces, and hence the pressure, is only slightly affected by the adjacent building. The influence of the distance between the buildings is strong at $\beta = 0^0$ but decreases rapidly with increasing wind angle.

Two buildings placed in line with the test building, Fig 6, cause a chanelling of air between the buildings at $0 \lesssim \beta \lesssim 30^0$ and thus a decrease in pressure over both the short faces and part of the leeward long face. At higher wind angles the effect of the upstream house is to reduce the overpressure on the windward short face of test building as well as the suction on the long faces.

The effects of two buildings located upwind of the test building, Fig 7, are most pronounced on the windward faces at $30^0 \lesssim \beta \lesssim 60^0$. At these wind angles there is also a strong influence of the distance, a, between the upwind buildings and the test building.

The results of the measurements made with the test building located at the centre of an array of identical buildings can be summarized as follows.

- One row of surrounding buildings causes a considerable change in the magnitude and distribution of wind pressure over all the test house walls and at all wind directions, as shown in Fig 8. Overpressures and underpressures are both smaller than for an isolated building and the distributions of pressure over the walls are smoother.

- The effect of adding another row of buildings to the group is less marked, except at $\beta \approx 30^0$, in which case the additional row blocks the air stream that would otherwise penetrate the first row of buildings. This results in lower pressures over the windward long face of the test building. The pressures over the other faces are not appreciably affected by the second row.

- The effect of decreasing the spacing between buildings in a group, while keeping the number of building rows constant, is to slightly reduce both the overpressures on the windward faces and the underpressures on the leeward faces of the test building.

5.2 Heat losses due to natural ventilation

The pressure data obtained form the wind tunnel tests have been used for the calculation of airchange rates and associated heat losses for the five house units in the test building as influenced by adjacent buildings, wind speed, wind direction and internal-external temperature difference. The results of these calculations are briefly reviewed in the following.

The heat losses, Q (=Q_e) from the five house units when the building is isolated, i.e. fully exposed to wind from all directions, are shown in Fig 11, as a function of wind angle and wind speed.

At wind speeds up to 2 m/s the heat loss is practically independent of the wind direction for all house units, the air infiltration rate being determined mainly by thermal forces. At higher wind speeds the wind forces become dominant and the heat loss increases strongly with wind speed at small wind angles. As the wind angle increases, the pressure difference between the windward and leeward walls becomes smaller and the ventilation loss decreases, except for the windward end unit where the increasing wind pressure on the windward short wall causes an increase in the air infiltration rate and hence in the ventilation loss.

The reduction of ventilation loss, ΔQ, due to the wind shelter offered by adjacent buildings, expressed in as nondimensional form as $\Delta Q/Q_e = r_Q$, is shown in Fig 12 as a function of the Froude number, Fr. Results are presented for the two end units and for the centre unit. Also shown in the figure is the variation of $(r_Q)_m$ - i.e the maximum value of r_Q, obtained at high Froude numbers - with wind angle β.

For the model configurations where one building is located upstream of the test building, Conf B11-14, Fig 12 a-d, r_Q decreases with increasing wind angle and with increasing distance, a, between the buildings, as could be expected. The maximum r_Q-value obtained at $\beta = 0^o$ varies from $(r_Q)_m \approx 0.7$ for a = 2 l to $(r_Q)_m \approx 0.2$ for a = 6 l. In the latter case the influence of the upstream building becomes negligible at $\beta \approx 30^o$.

With two buildings placed in line with the test building, Conf C11-14, Fig 12 e-g, the acceleration of the air flow between the buildings results in low wind pressures over the short faces at wind angles up to $\beta \approx 30^o$, and hence an increase of the ventilation loss from the end units ($r_Q < 0$). At higher wind angles the upwind building causes a reduction of the ventilation loss, the largest r_Q-value, $r_Q \approx 0.5$, being obtained for the windward end unit in model Conf C11 at $\beta = 90^o$.

Two buildings upwind, as in Conf D11-14, have little effect on the ventilation loss from the test building at $\beta = 0^o$. As the wind angle increases the wake of the upwind building successively affects the wind pressures, and thus the ventilation loss, on the different house units of the test building, as shown in Fig 12 h-j. The maximum shelter effect, corresponding to an r_Q-value of about 0.3, is obtained at a wind angle between

30^{0} and 60^{0}, depending on the location of the house unit and the separation between the buildings.

When the test building is located at the centre of an array of identical buildings, the effects of these buildings on the ventilation losses from the different house units become very complex, as illustrated in Fig 12 k-n. Some general observations can, however, be made:

- With one row of buildings around the test building and a separation of a = b = 1, the r_Q-values lie between 0.2 (windward en unit) and 0.7 (centre unit) depending on the wind angle. With a separation of a = b = 2 l the corresponding r_Q-values are 0.1 and 0.5.

- With two rows of buildings surrounding the test building the influence of the wind direction is less pronounced. The r_Q-values range from 0.2 to 0.7 at a separation of a = b = 1 and from 0.1 to 0.4 at a = b = 2 l, the higher r_q-values being obtained for the centre unit.

6. CONCLUSIONS

Adjacent buildings have been shown to have a large effect on the magnitude and distribution of wind pressures over the row of 2-storey terrace houses studied in the tests. Pressure coefficients relating to an isolated building, as those given in the Swedish Building Code, SBN 80, will therefore yield unrealistic results when used for the calculation of wind-induced ventilation losses from a building located in a built-up area.

The results of the calculation of ventilation losses from the terrace houses, based on pressure coefficients obtained from the present study, may be summarized as follows:

(1) The wind-induced ventilation losses from the house units in an isolated row of houses can be considered to be independent of wind direction for wind speeds up to about 2 m/s, i.e. at low Froude numbers, with the exception of the windward end unit where the ventilation loss is practically unaffected by wind direction at all wind speeds.

(2) The reduction of ventilation loss due to adjacent buildings is presented in a non-dimensional form as a reduction coefficient $r_Q = \Delta Q/Q_e$ which can be regarded as independent of the airtightness of the house. For a given wind direction r_Q is shown to depended only on a densimetric Froude number based on wind speed and internal-external temperature difference. When combined with local wind statistics, the sum of r_Q-values for the different buildings in a group provide a basis for a choice between alternative site plans in a planned development if wind-related energy losses are to be minimized.

(3) Even when the row of houses is situated at the centre of a fairly dense group of buildings, there is a considerable difference in r_Q between the different house units and a strong influence of wind direction. The highest r_Q-values are characteristically those relating to the centre unit for which a maximum r_Q-value of 0.7 has been obtained.

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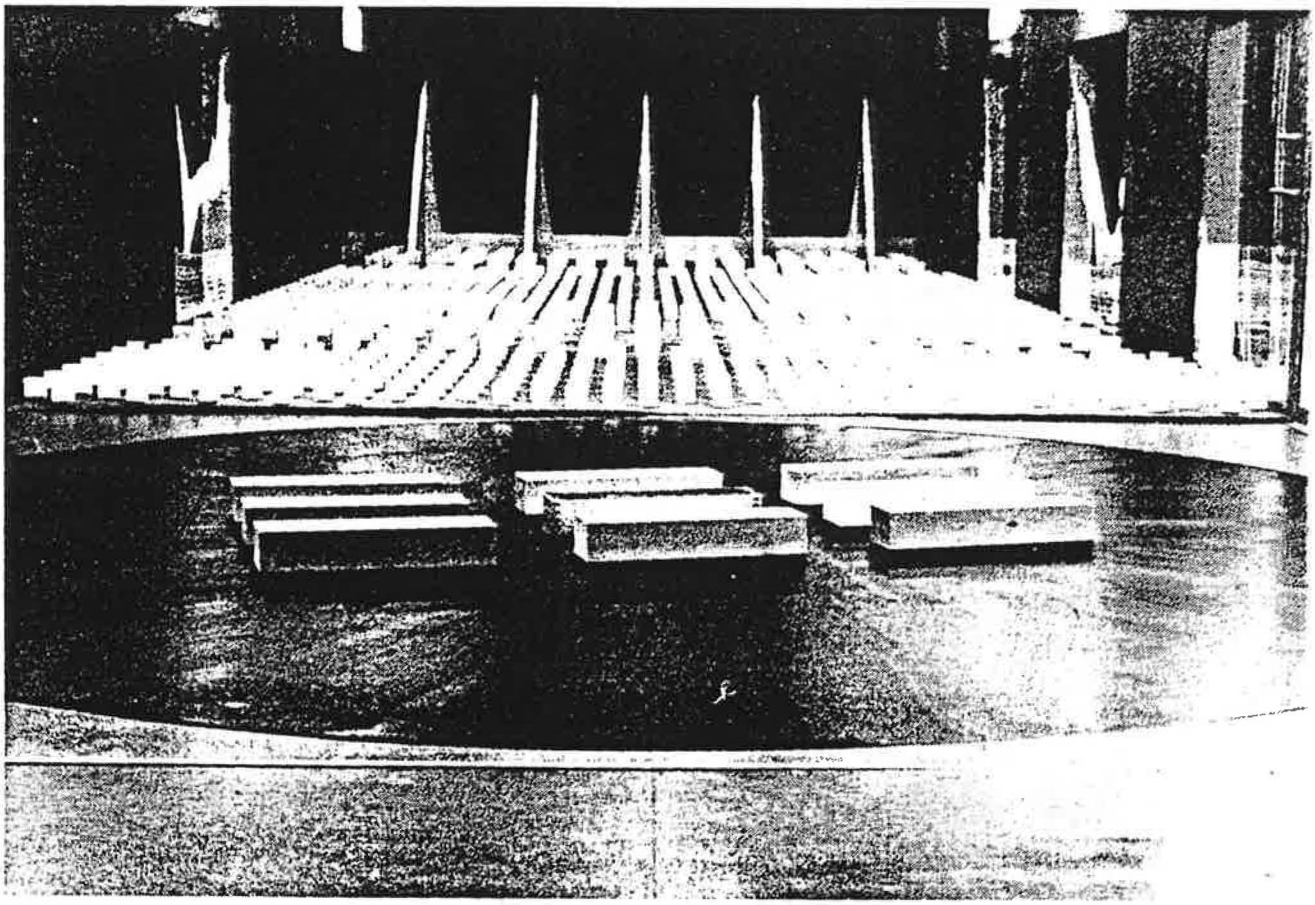


Fig.1 Wind tunnel installation

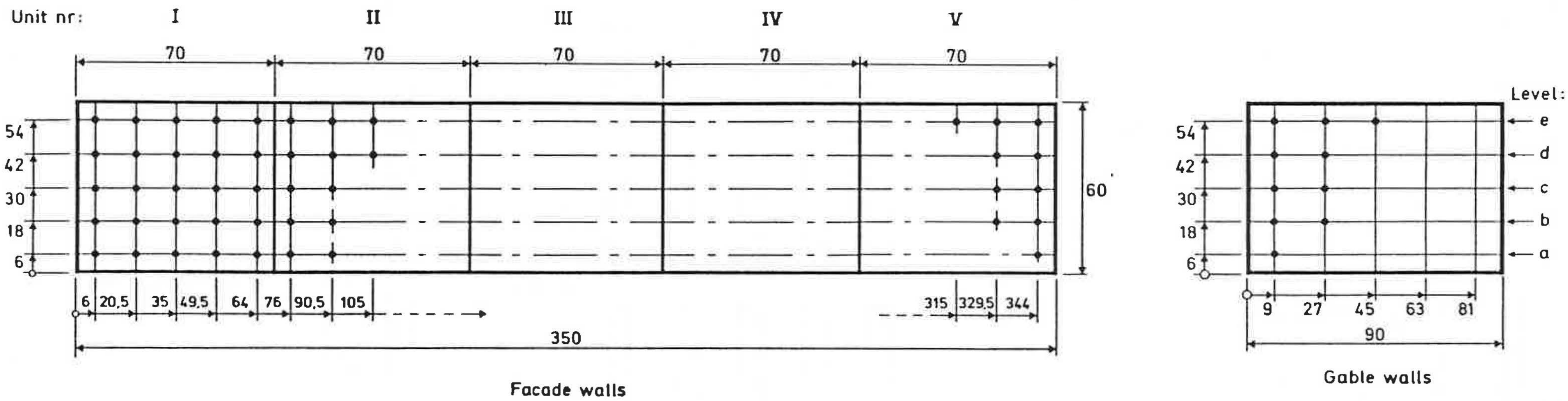


Fig.2 Model dimensions and location of pressure taps

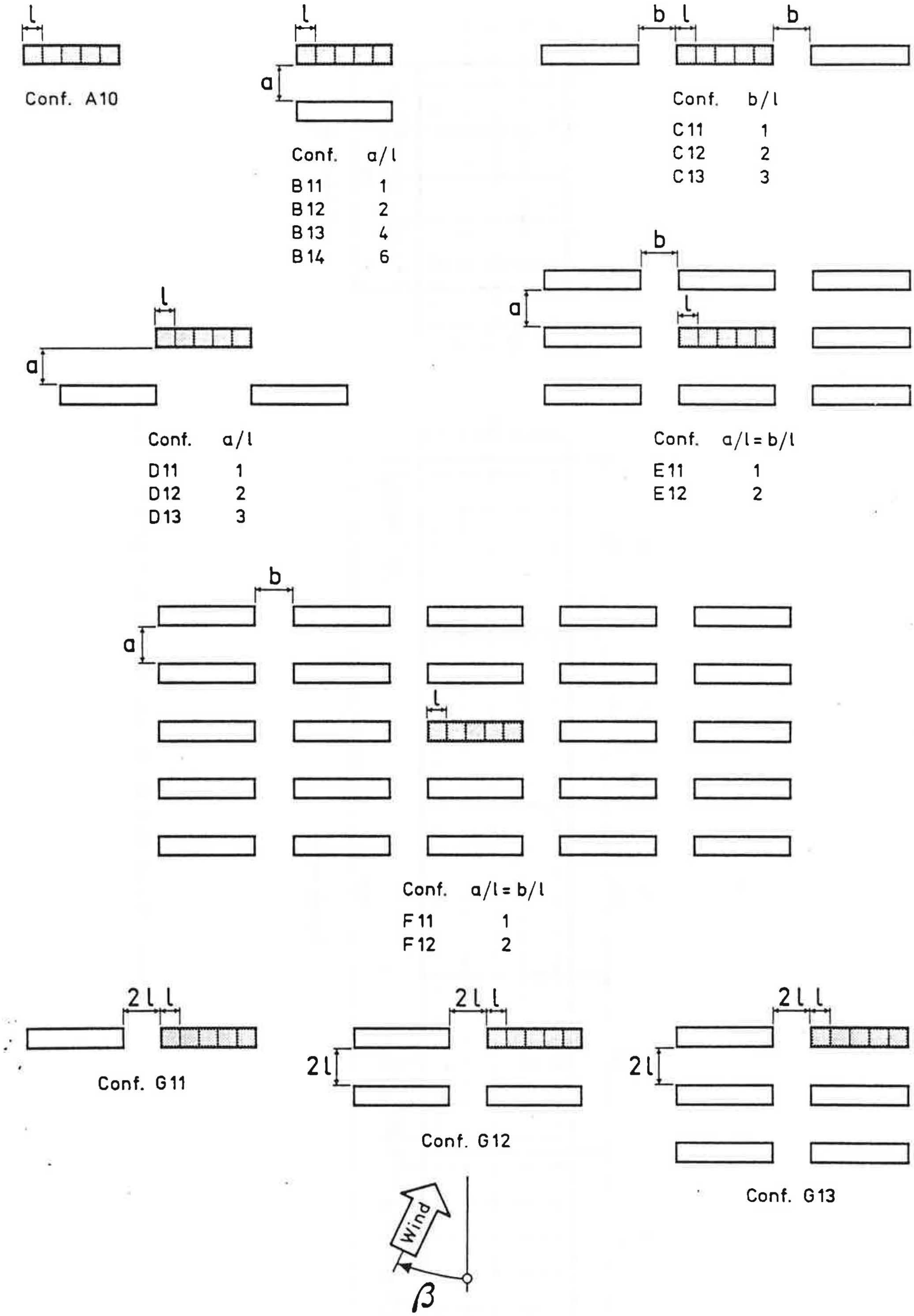
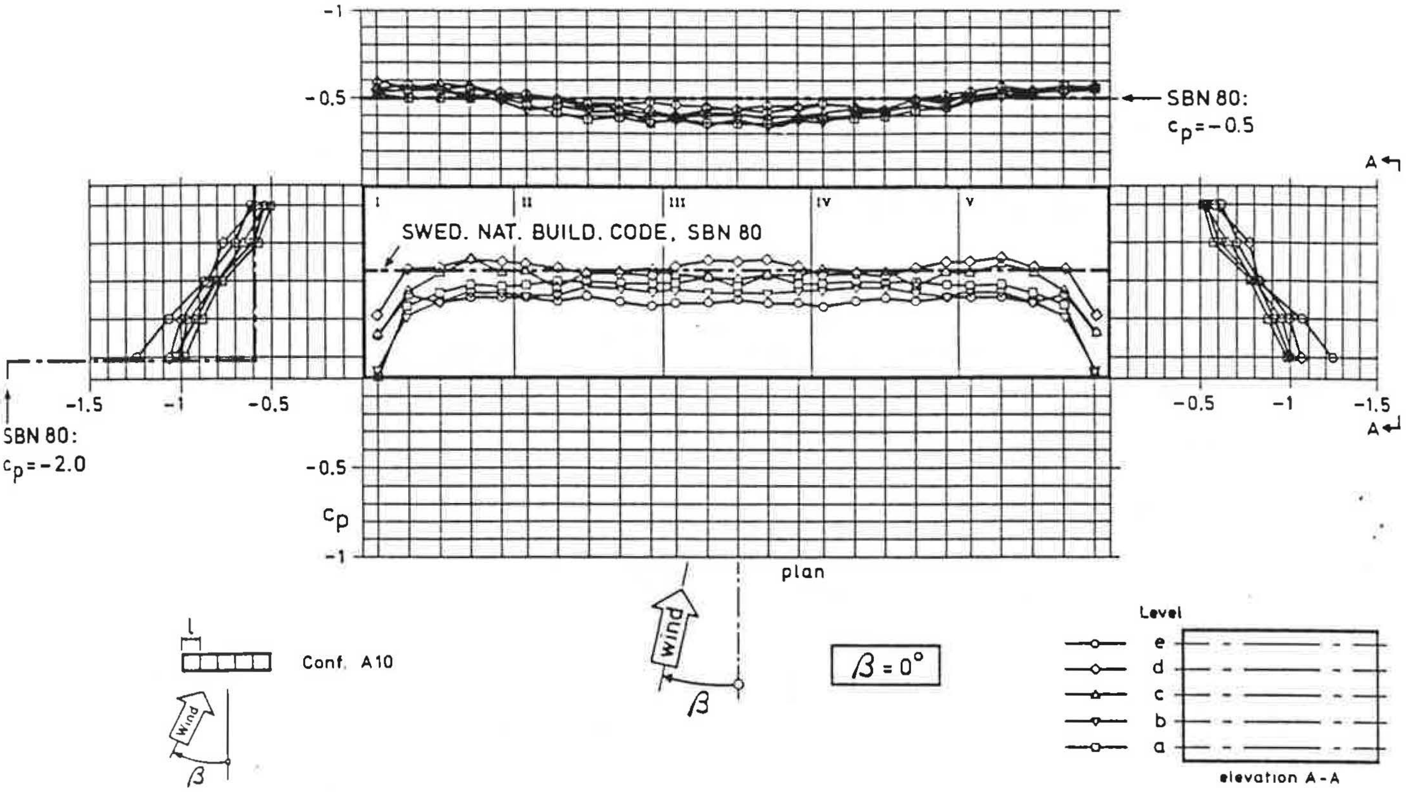


Fig.3 Model configurations (layout patterns).



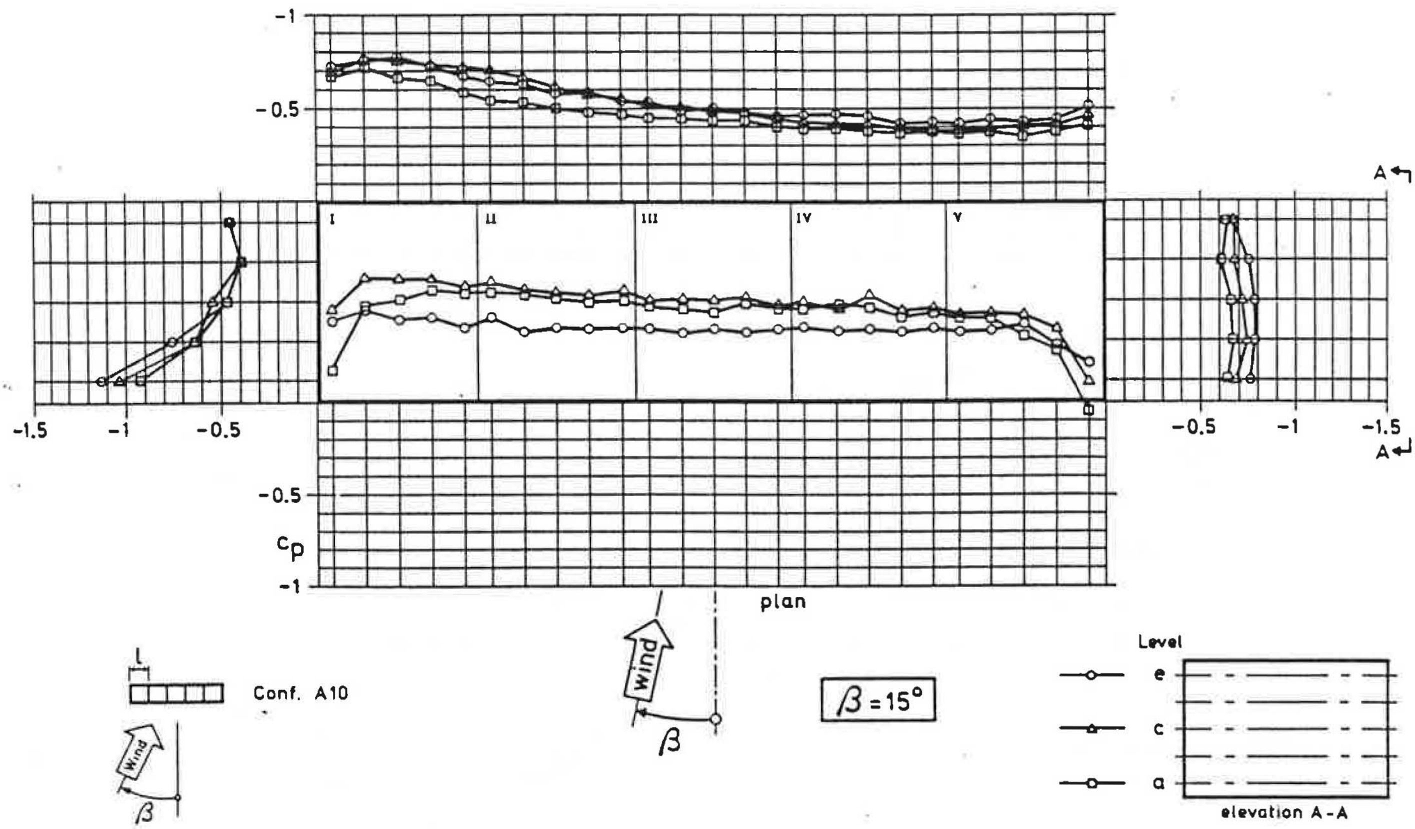
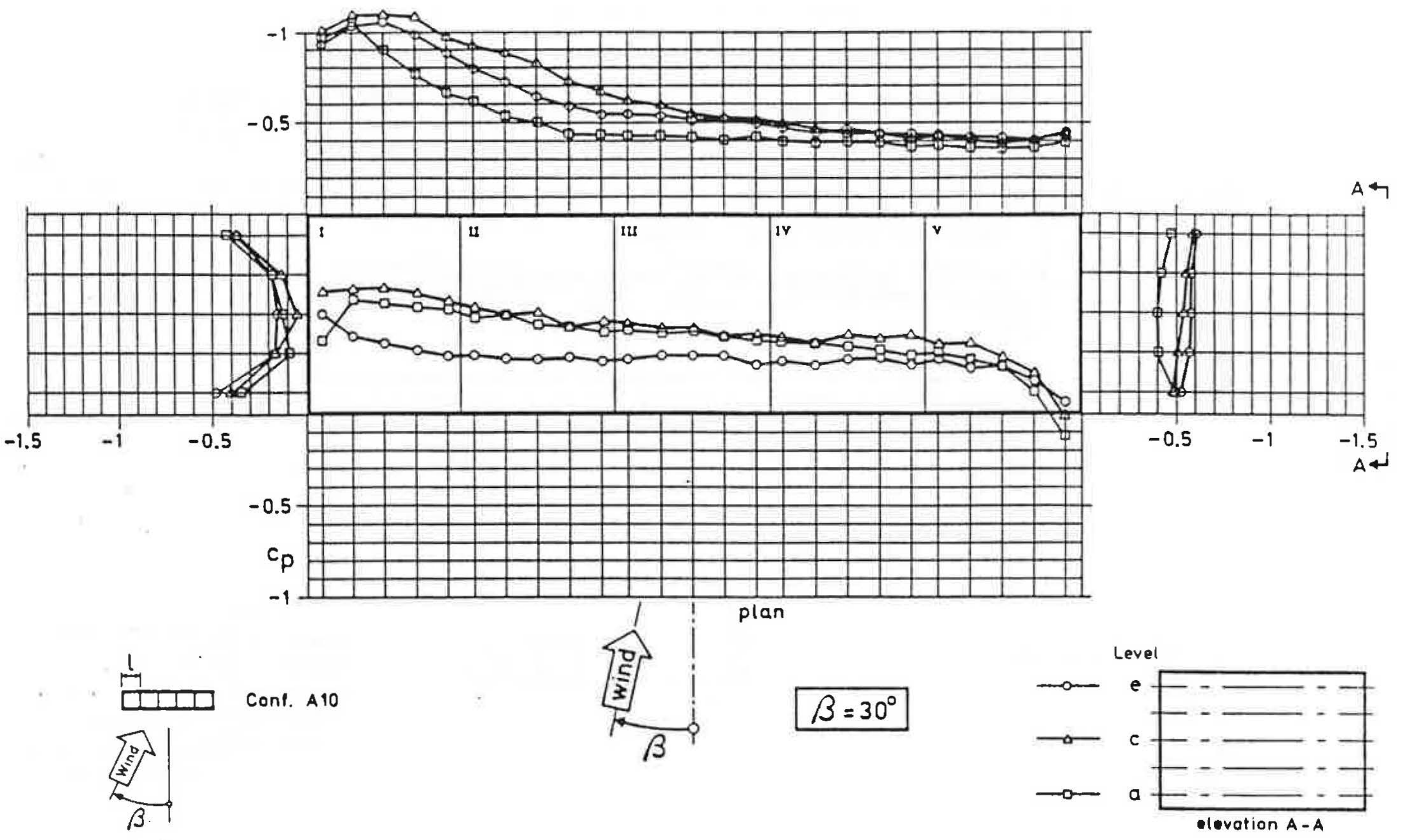


Fig.4 Mean-pressure distributions over the model walls. Config. A10

a. Wind angle β=0° and 15°



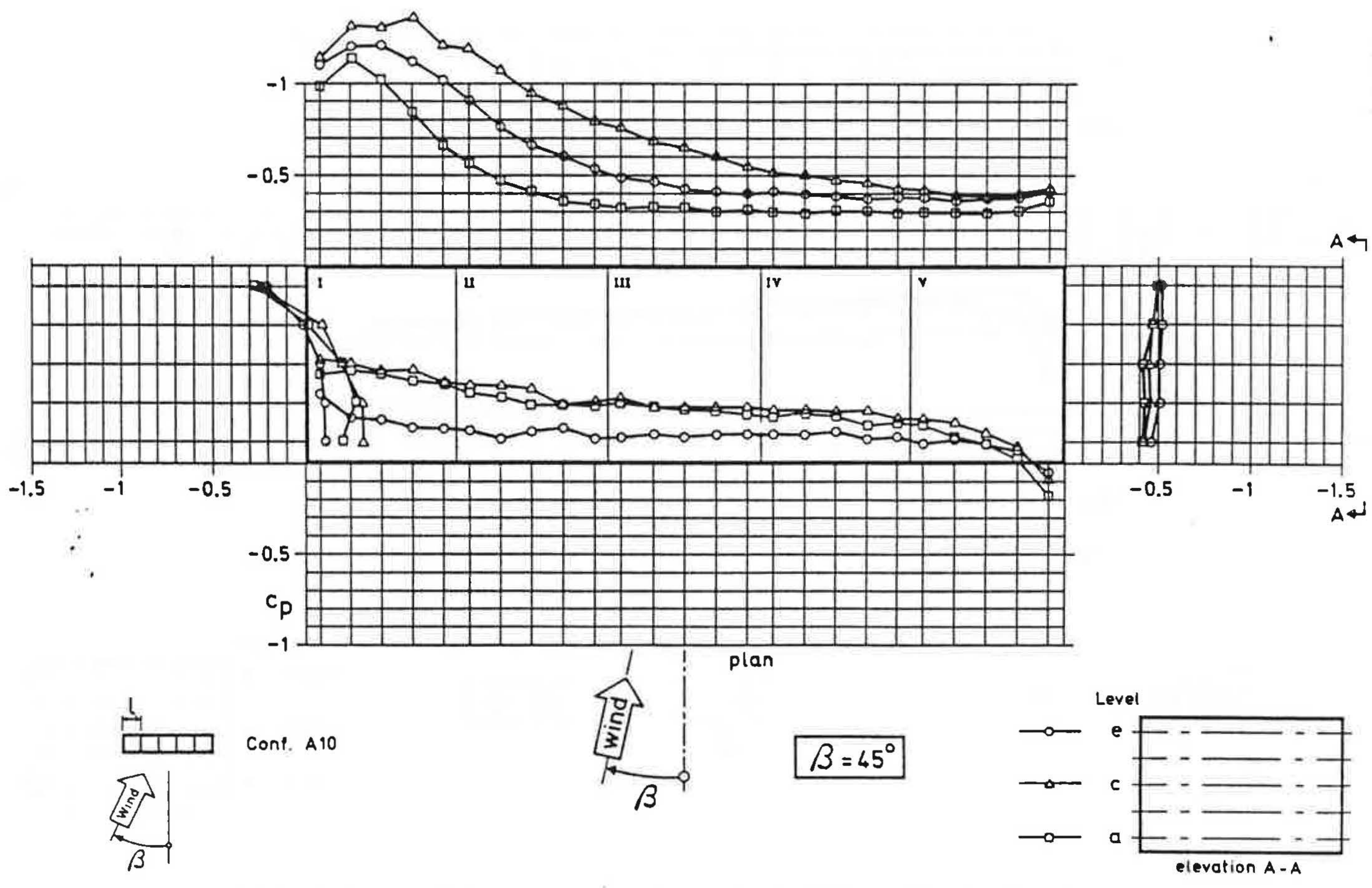
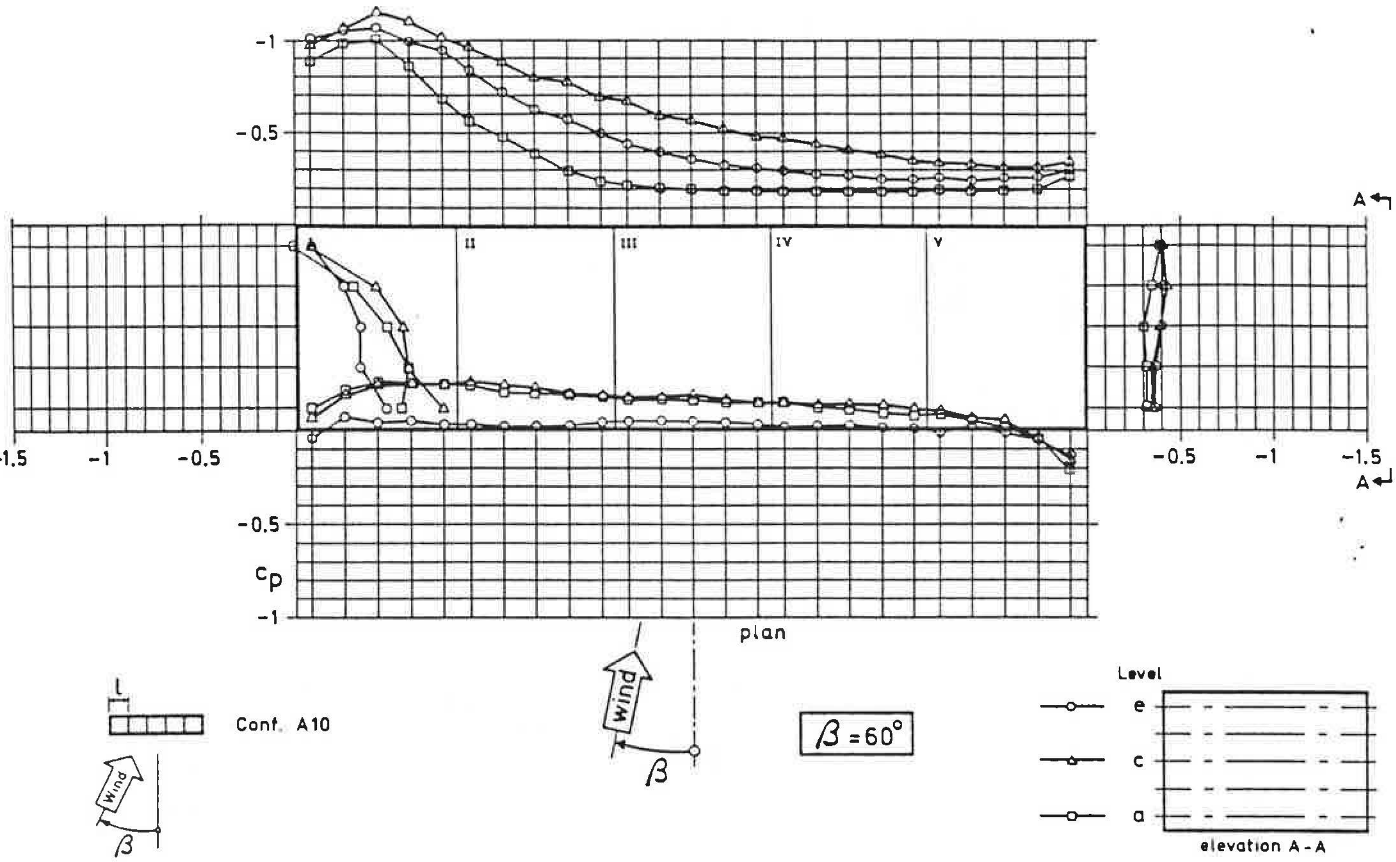


Fig.4 Cont´d

b. Wind angle $\beta = 30^{\circ}$ and 45°



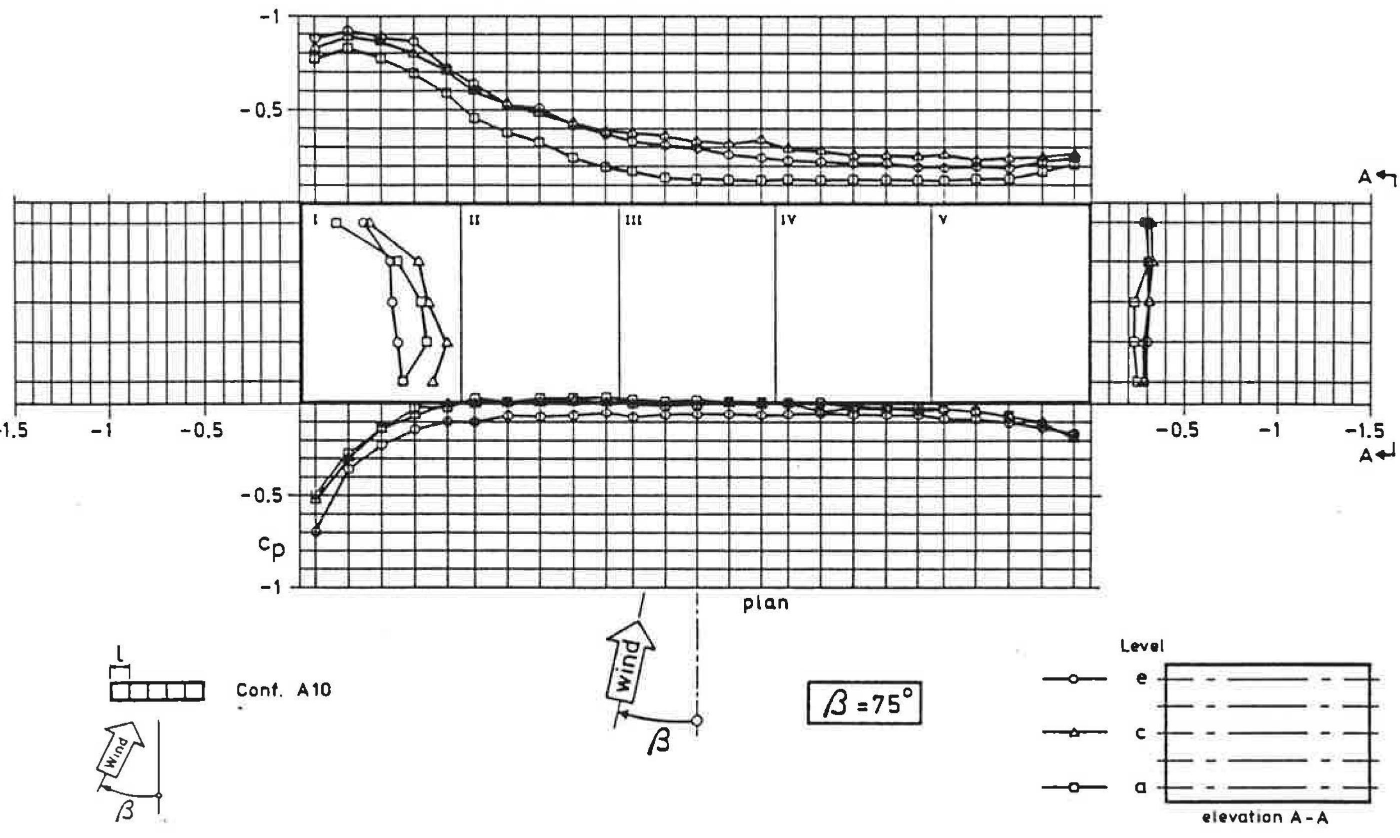


Fig.4 Cont´d

c. Wind angle β =60° and 75°

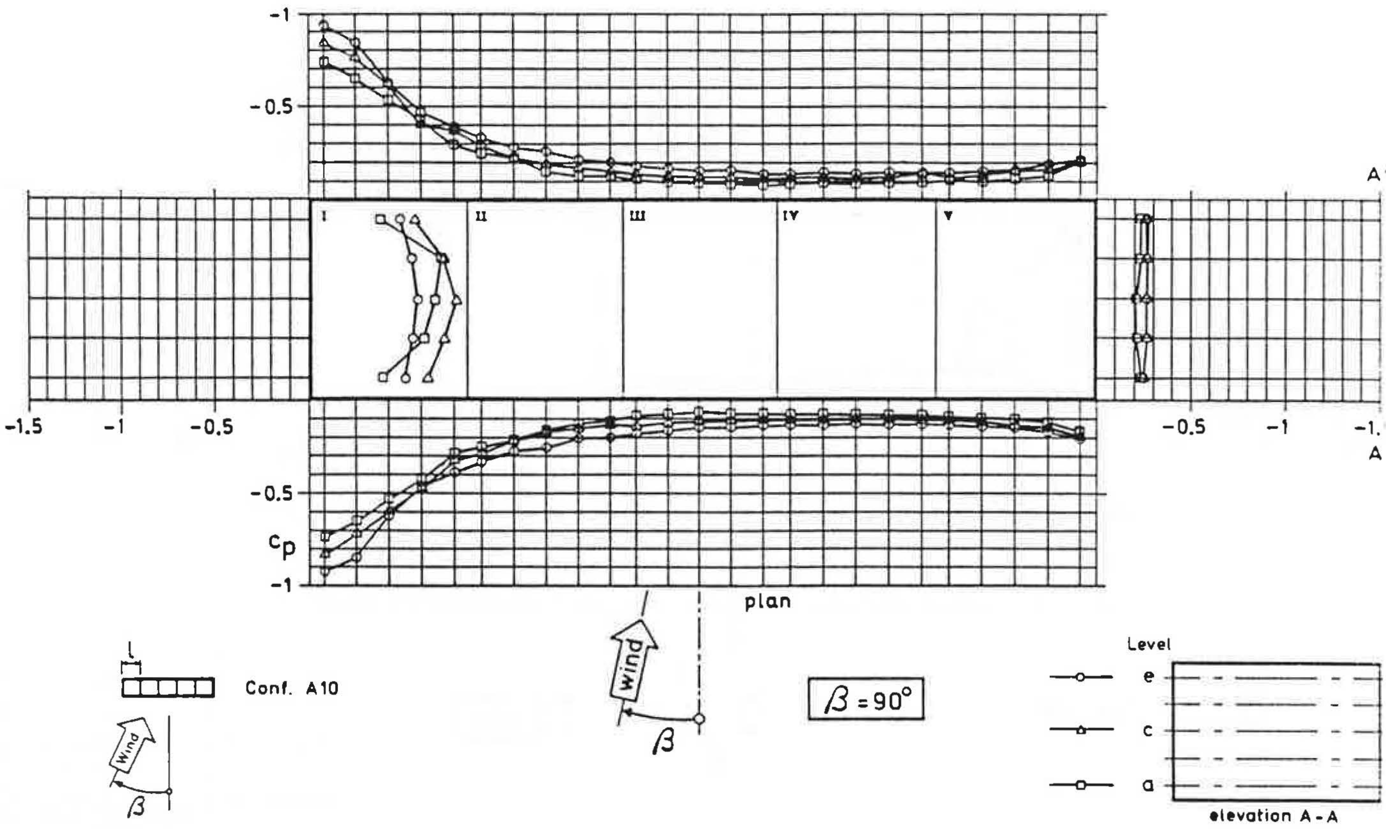
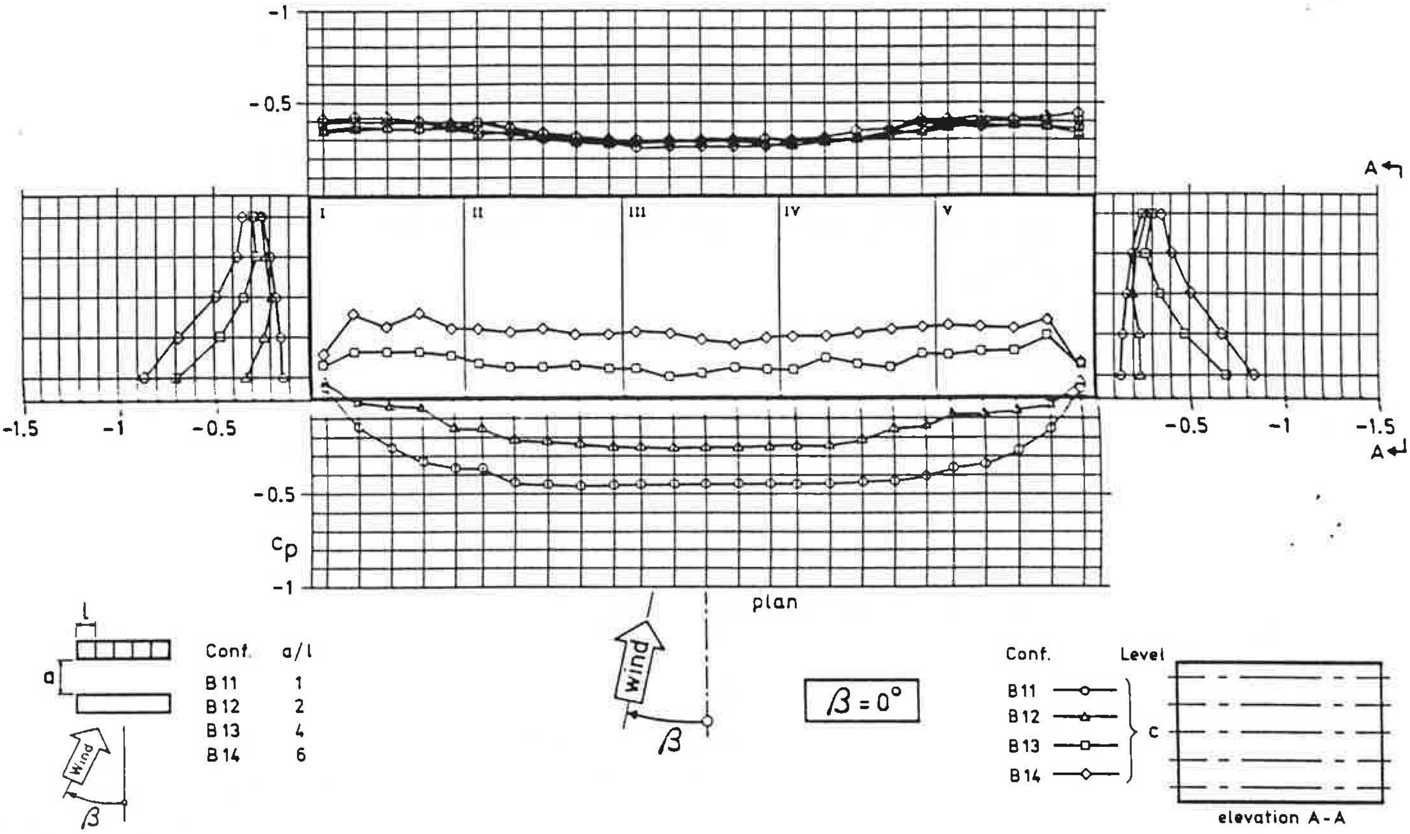


Fig.4 Cont´d

d. Wind angle $\beta = 90^{\circ}$



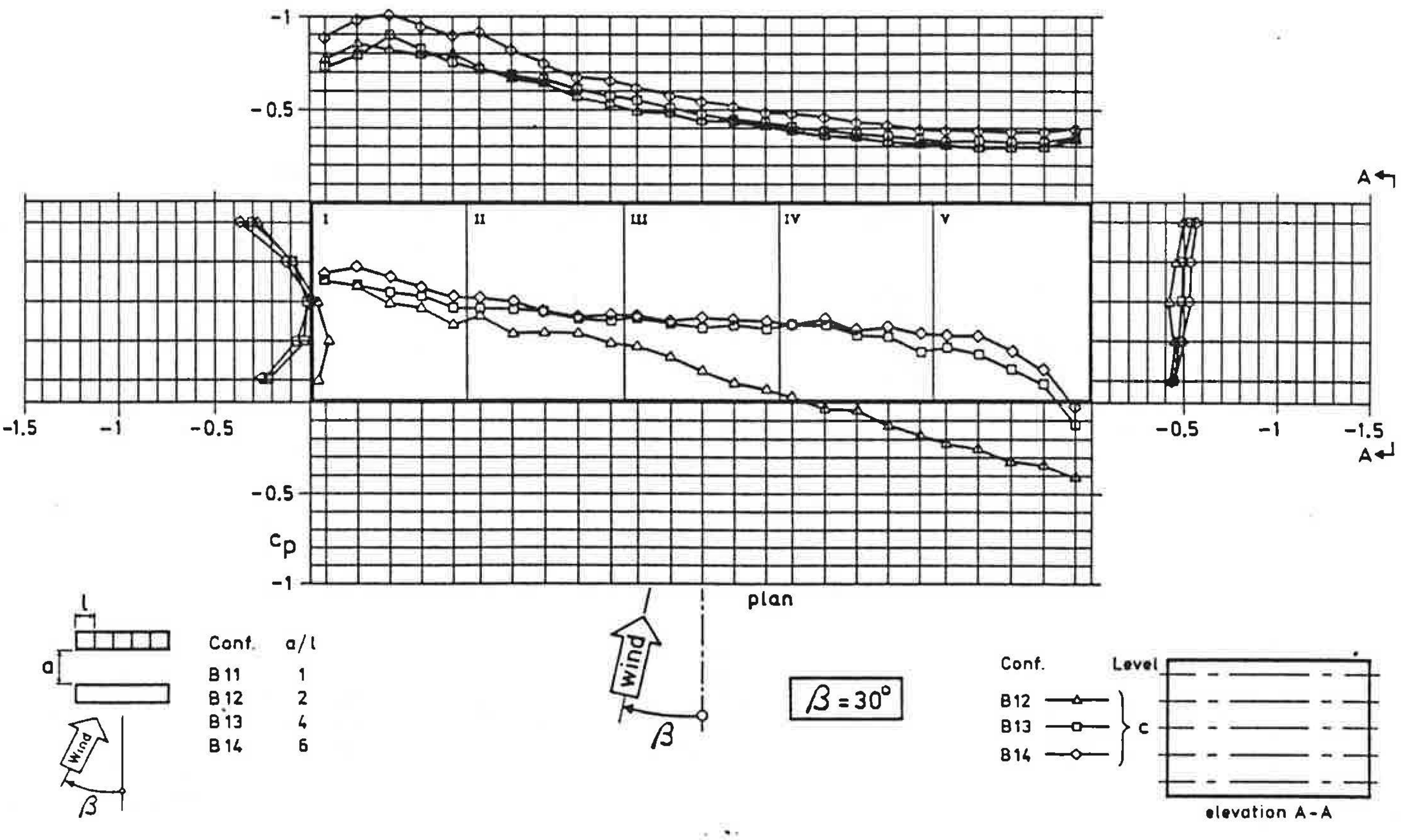
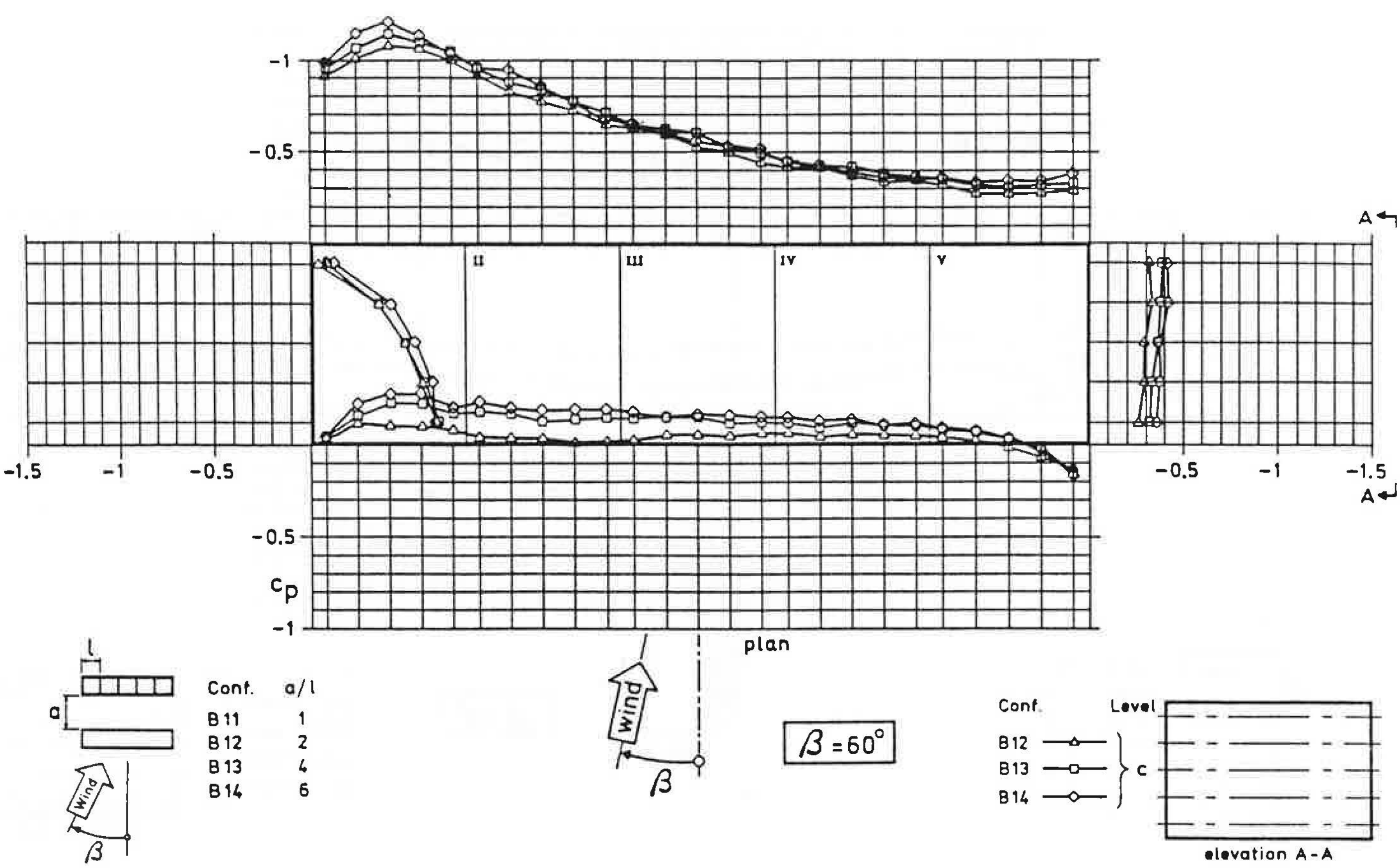


Fig.5 Mean-pressure distributions over the model walls.
Config´s B11–B14

a. Wind angle $\beta = 0^{\circ}$ and 30°



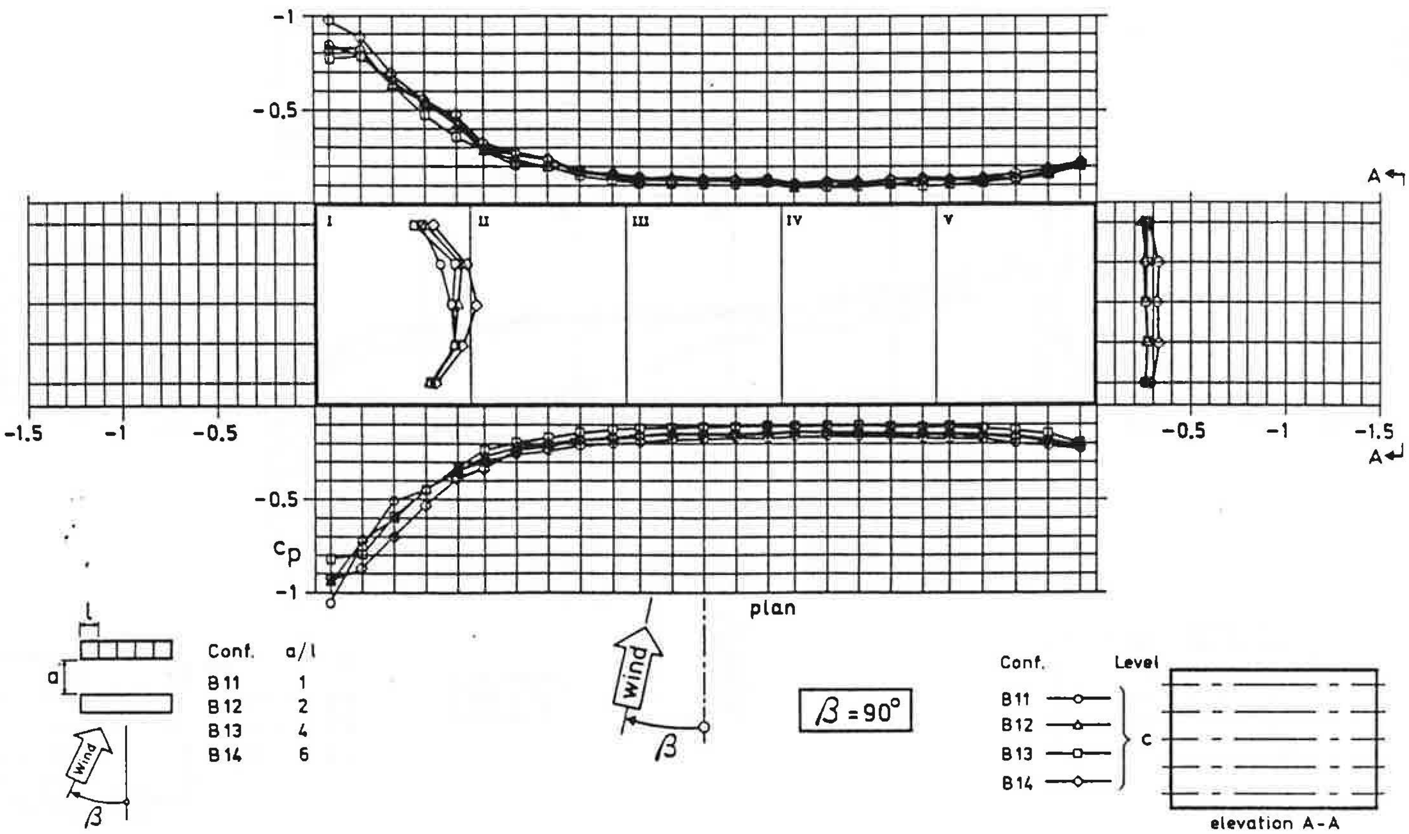
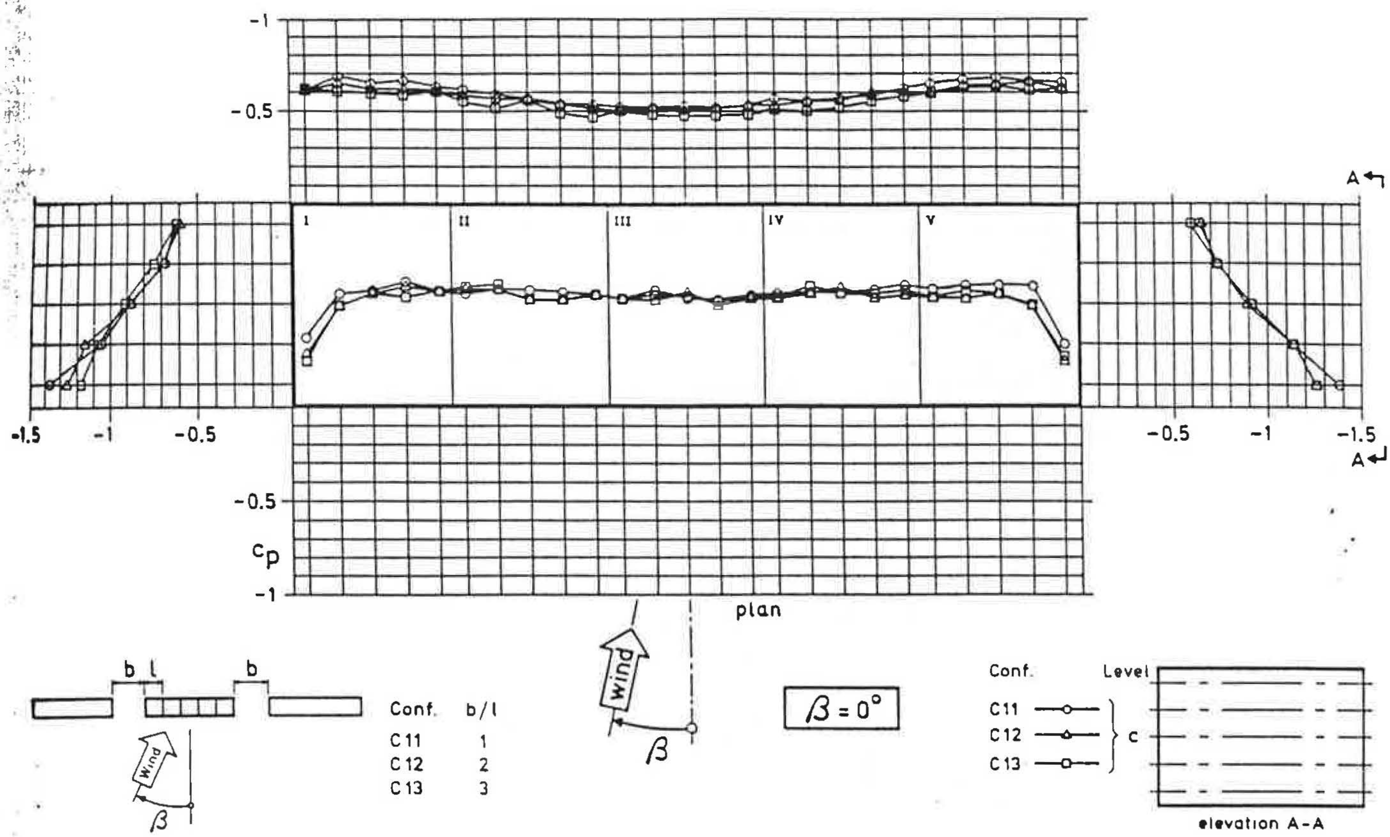


Fig.5 Cont´d

b. Wind angle $\beta = 60^{\circ}$ and 90°



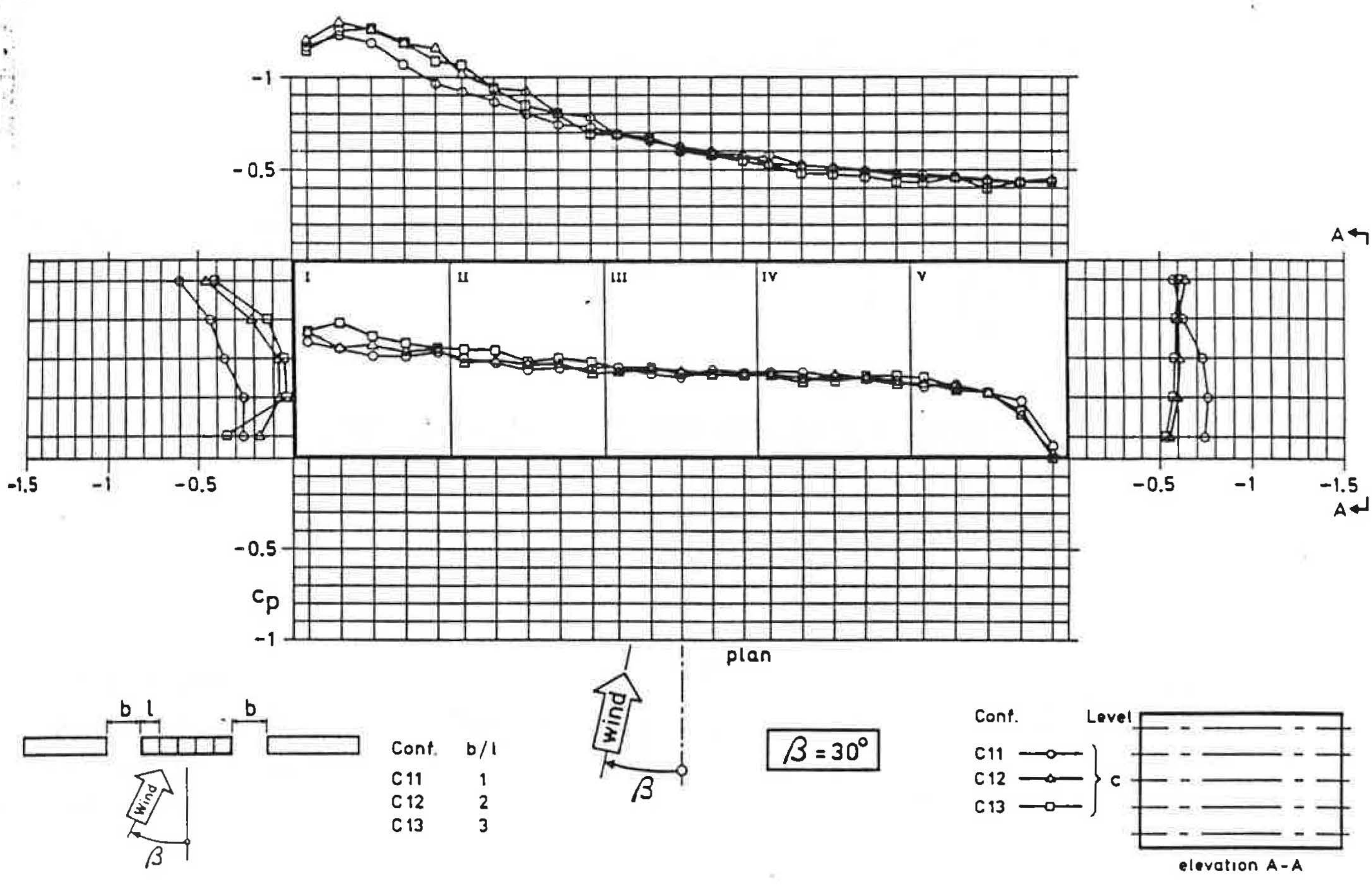
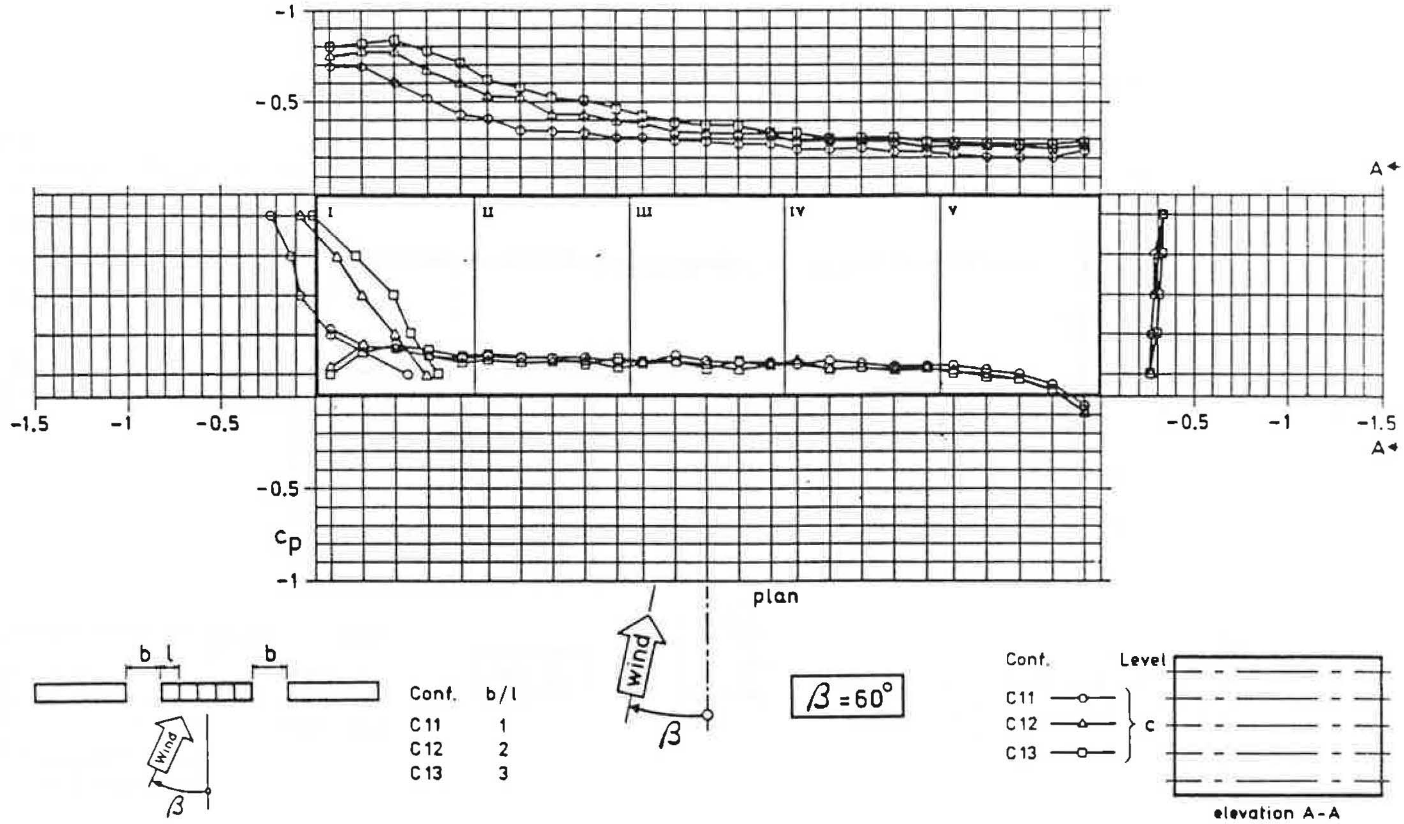


Fig.6 Mean-pressure distributions over the model walls.
Config´s C11-C13

a. Wind angle $\beta = 0^{\circ}$ and 30°



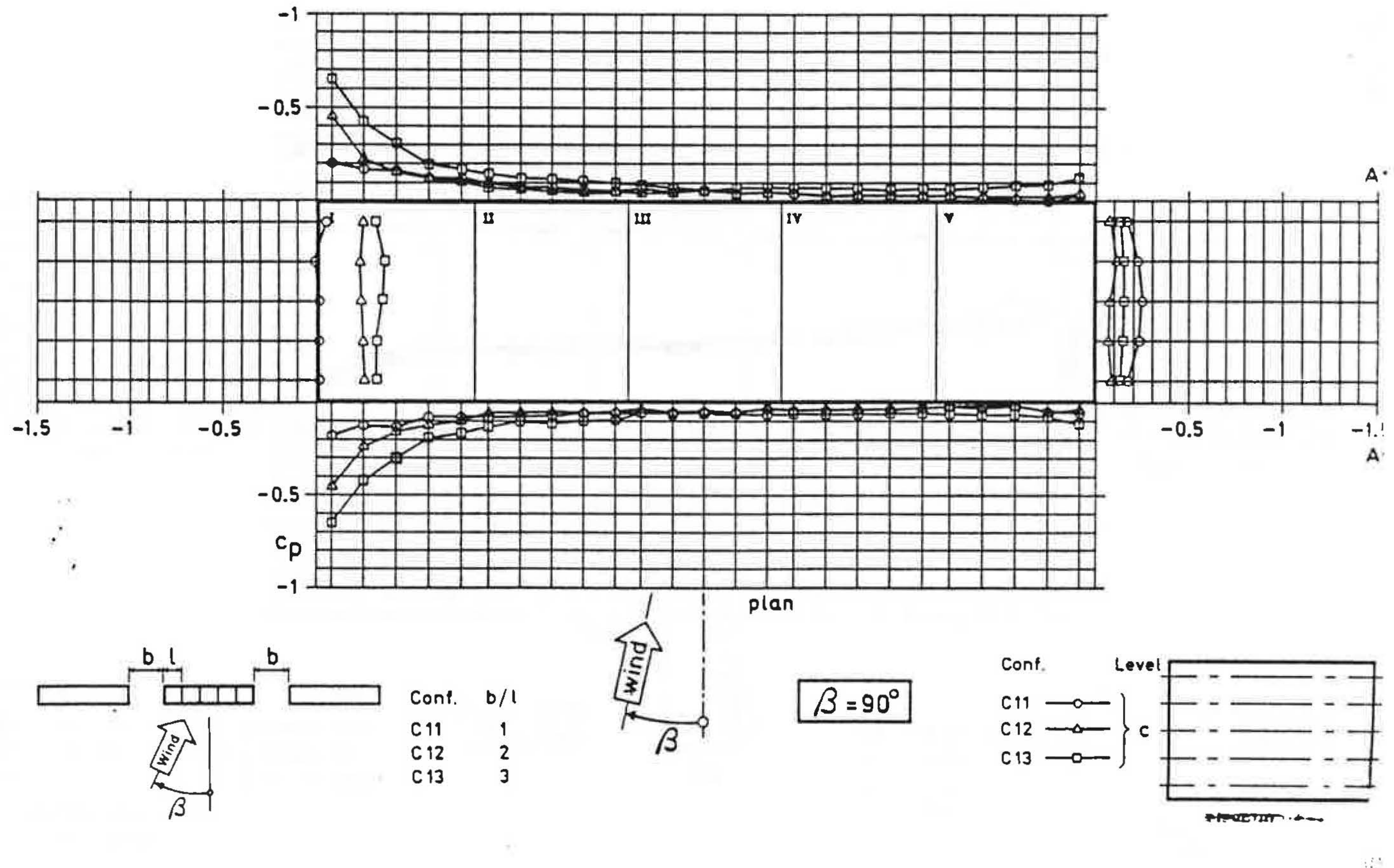
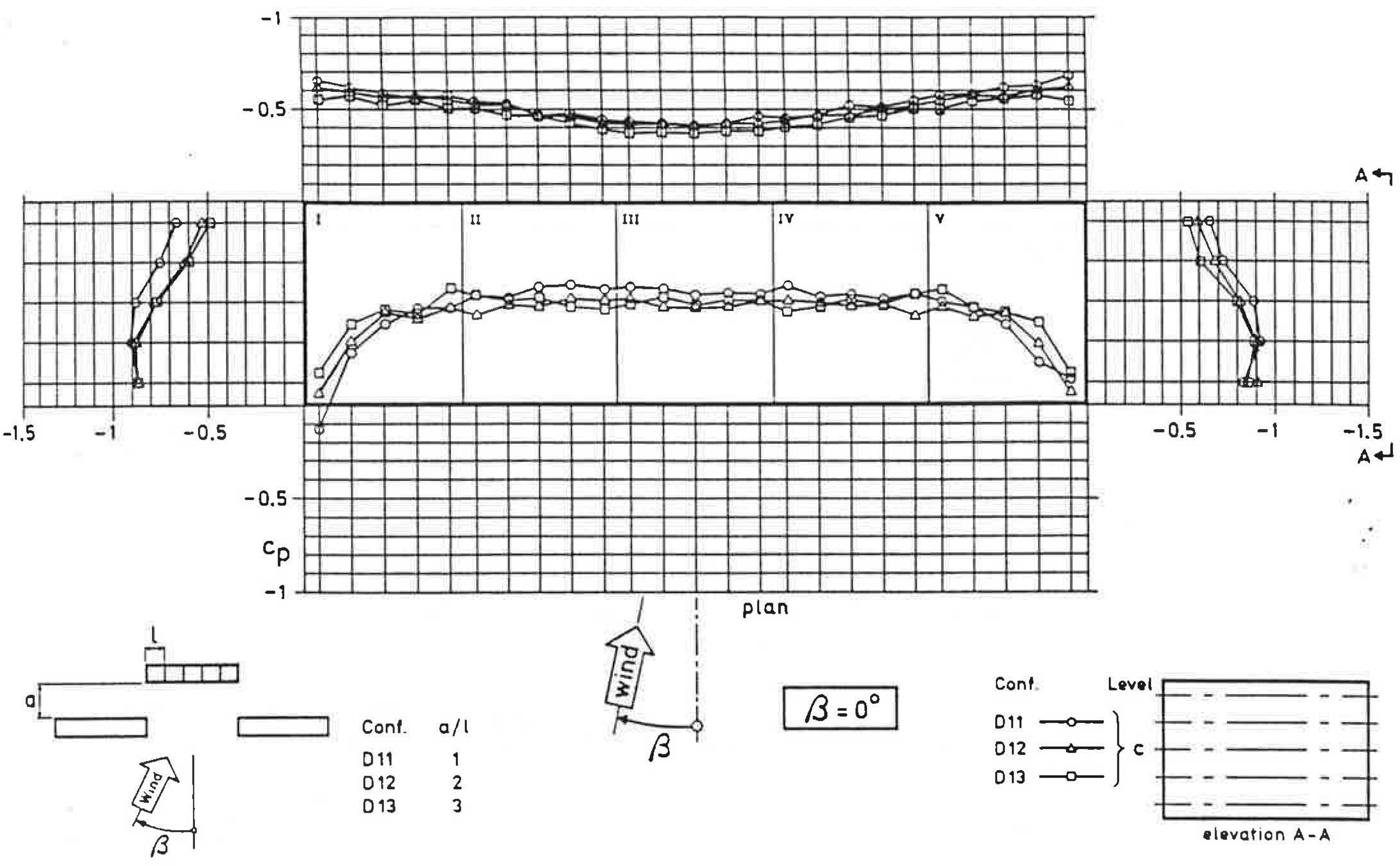


Fig.6 Cont´d

b. Wind angle β =60° and 90°



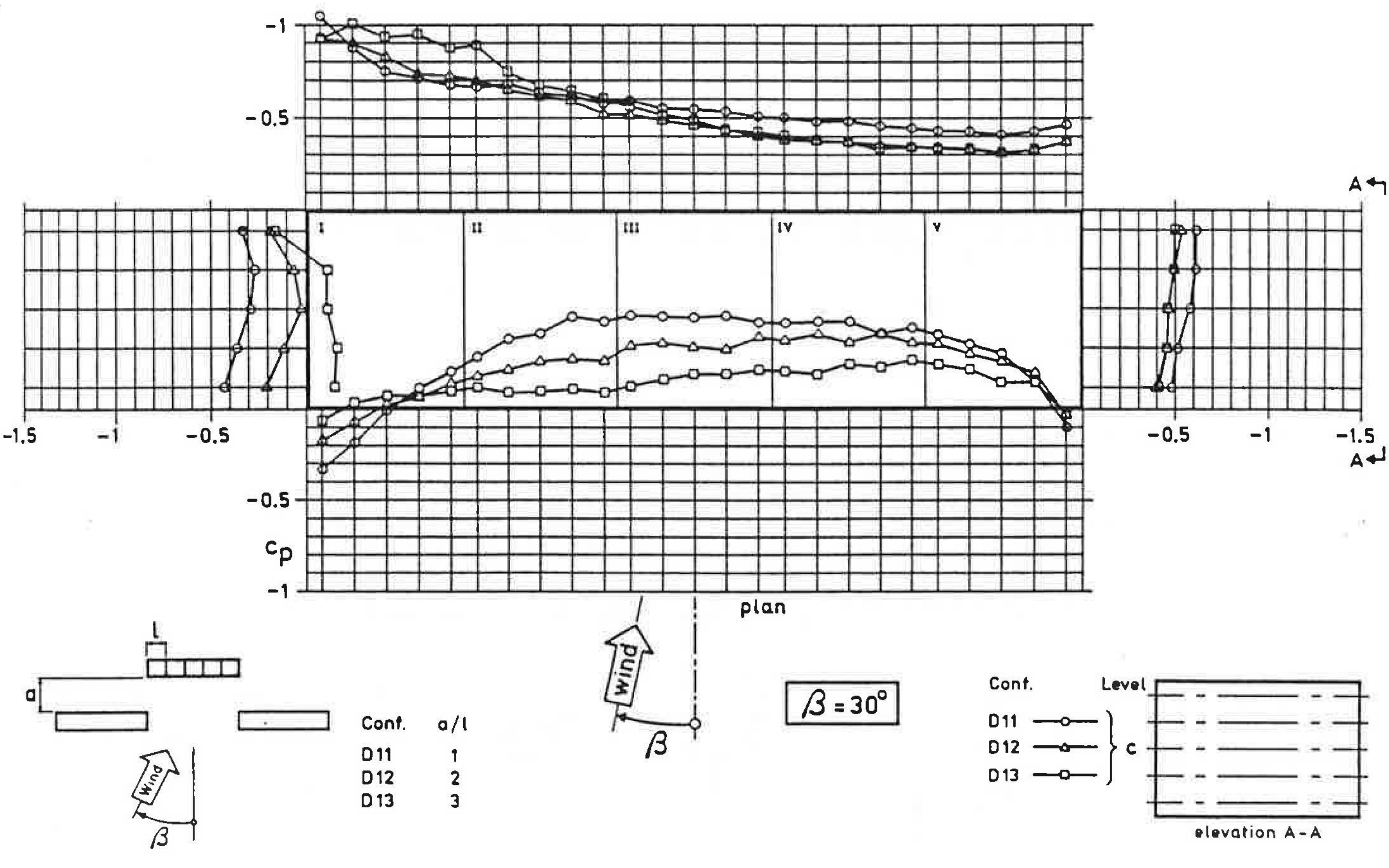
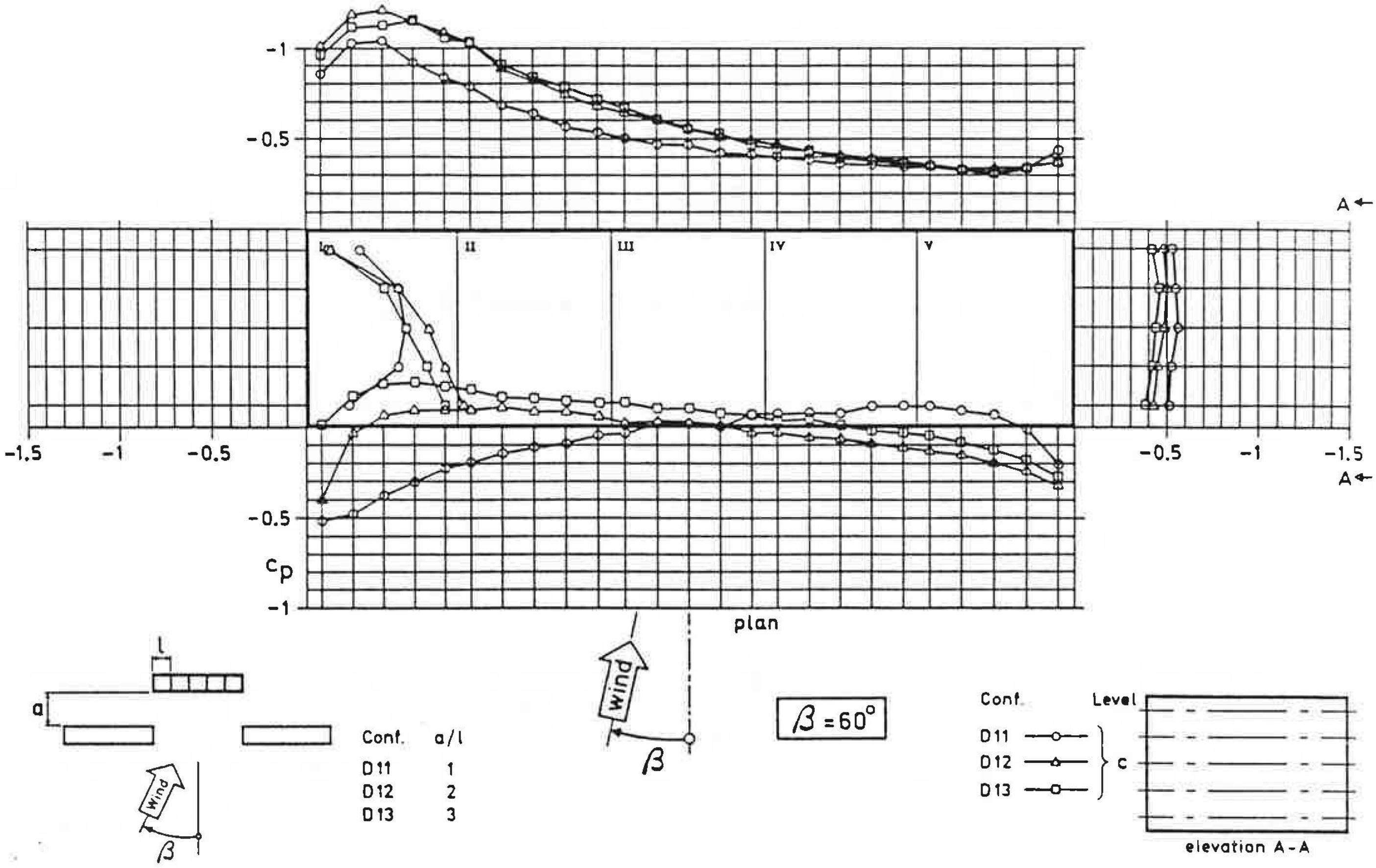


Fig.7 Mean-pressure distributions over the model walls.
Config´s D11-D13

a. Wind angle $\beta = 0^{\circ}$ and 30°



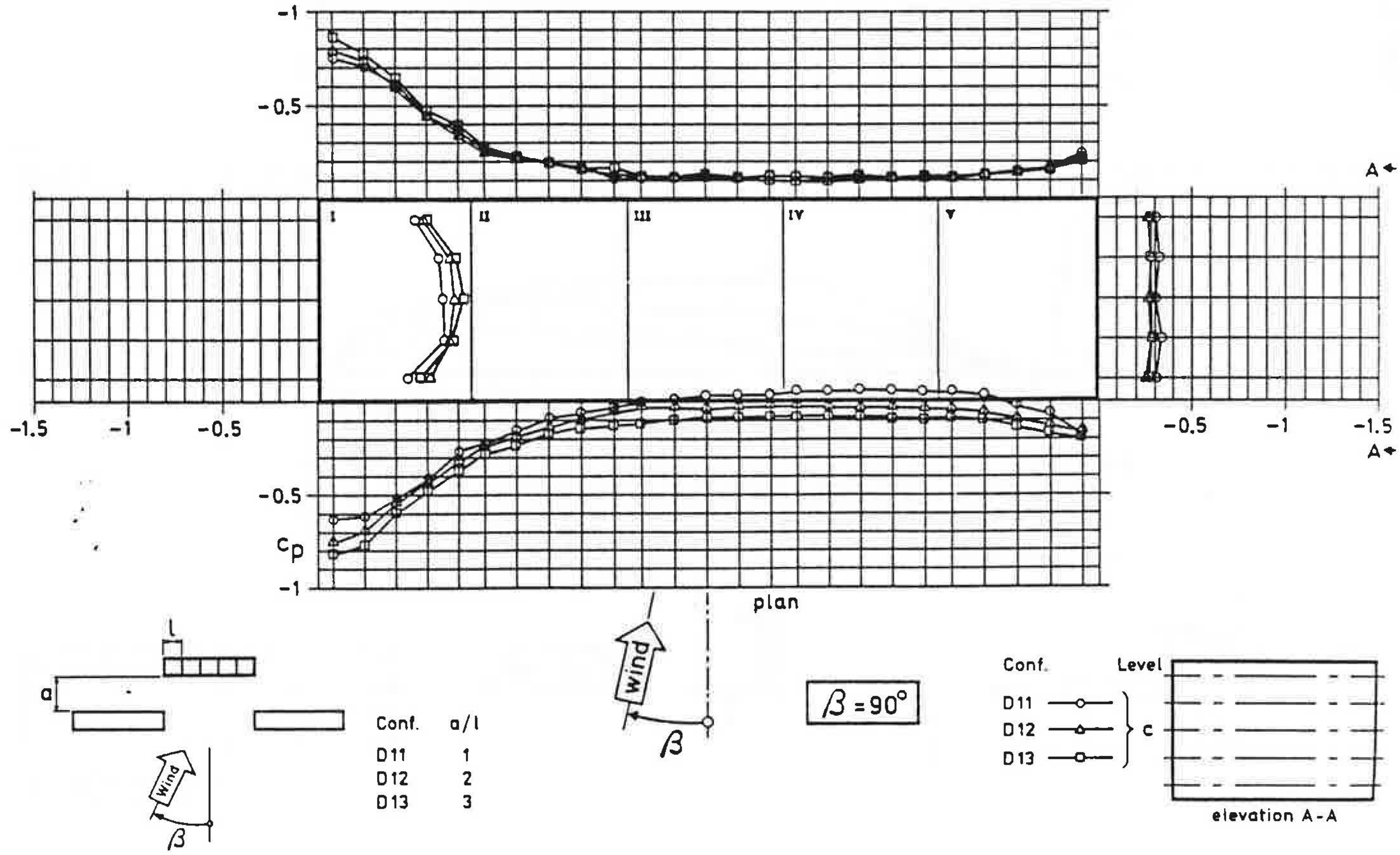
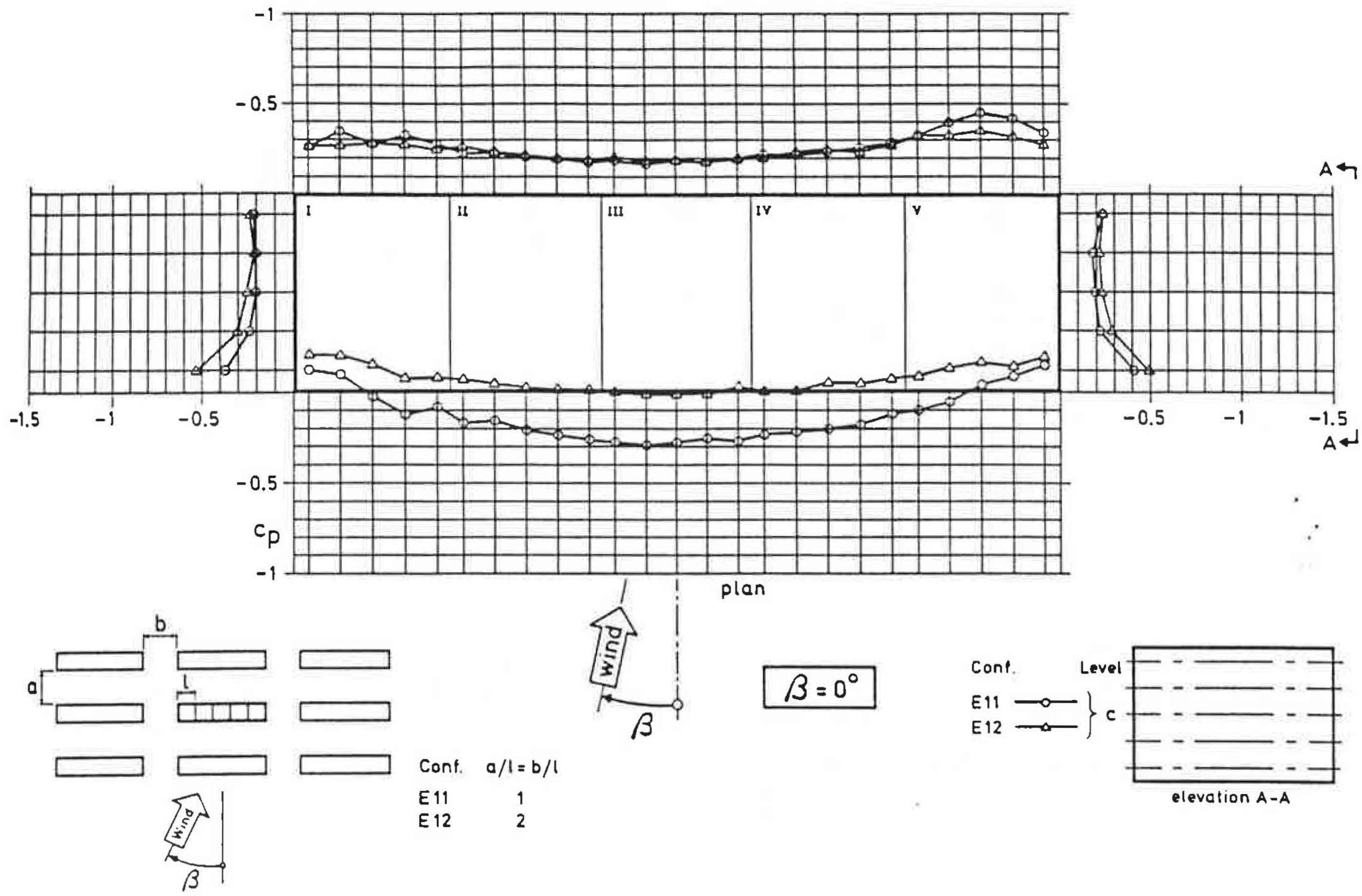


Fig.7 Cont´d

b. Wind angle β=60° and 90°



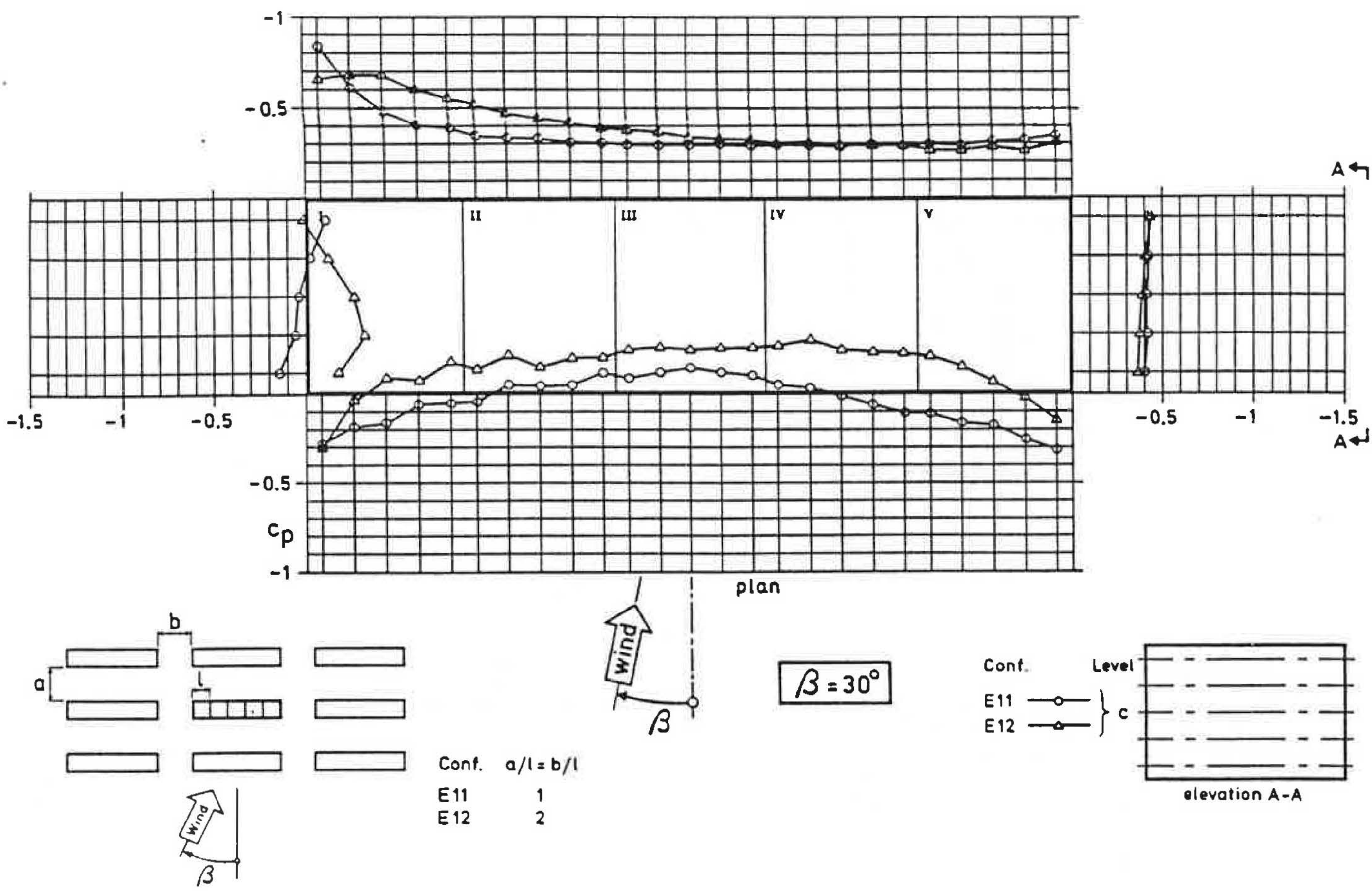
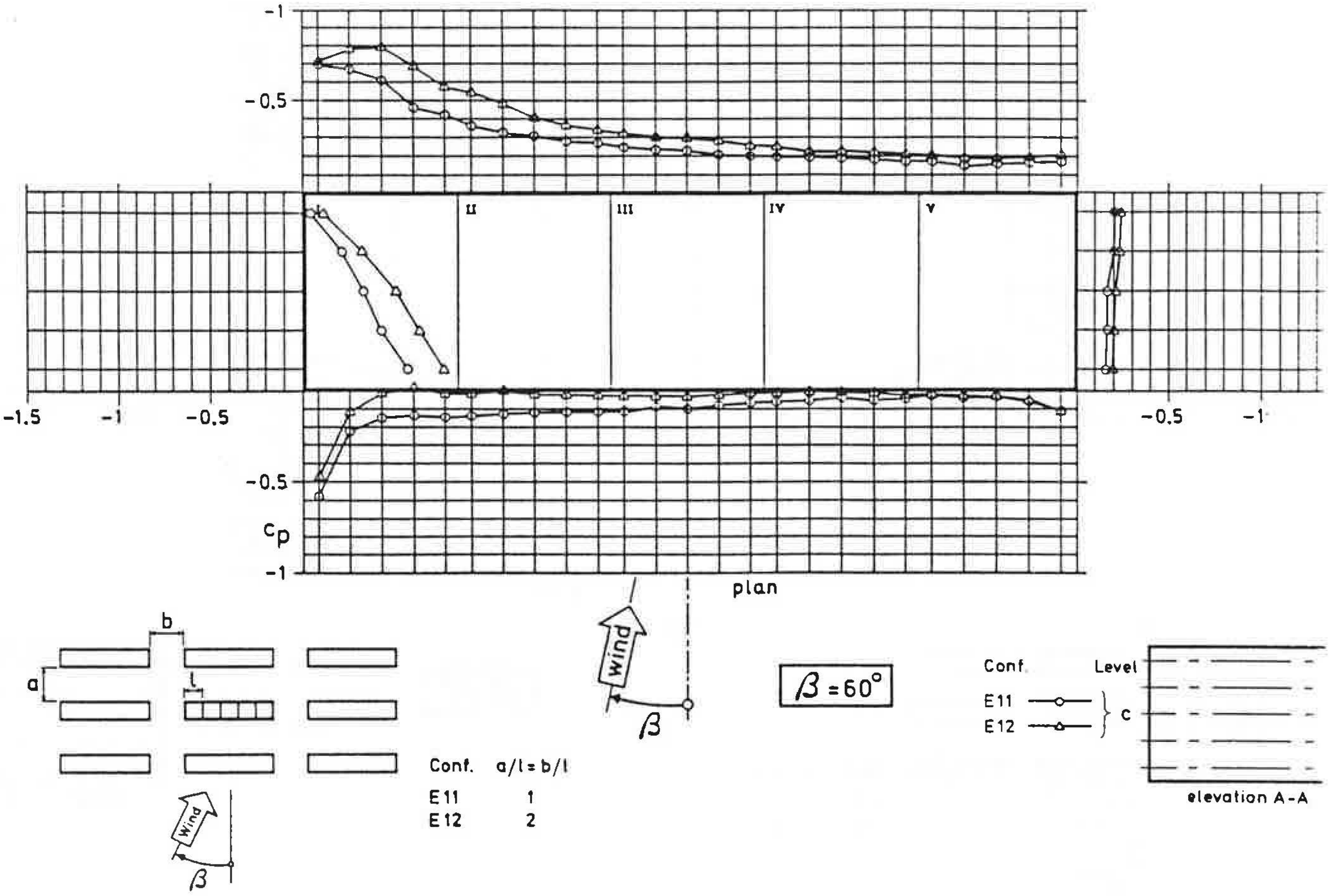


Fig.8 Mean-pressure distributions over the model walls.
Config's E11 and E12

a. Wind angle $\beta = 0^{\circ}$ and 30°



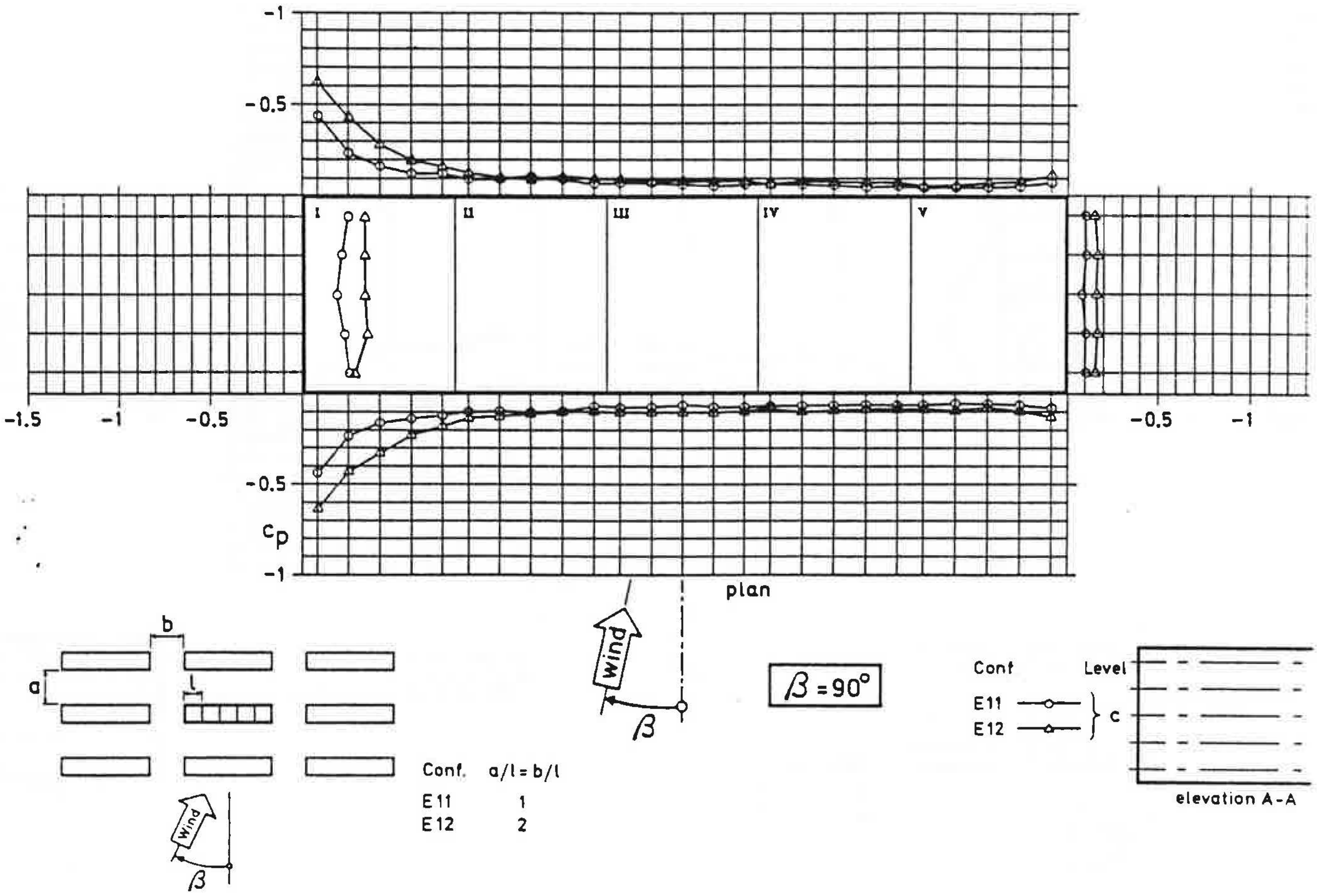
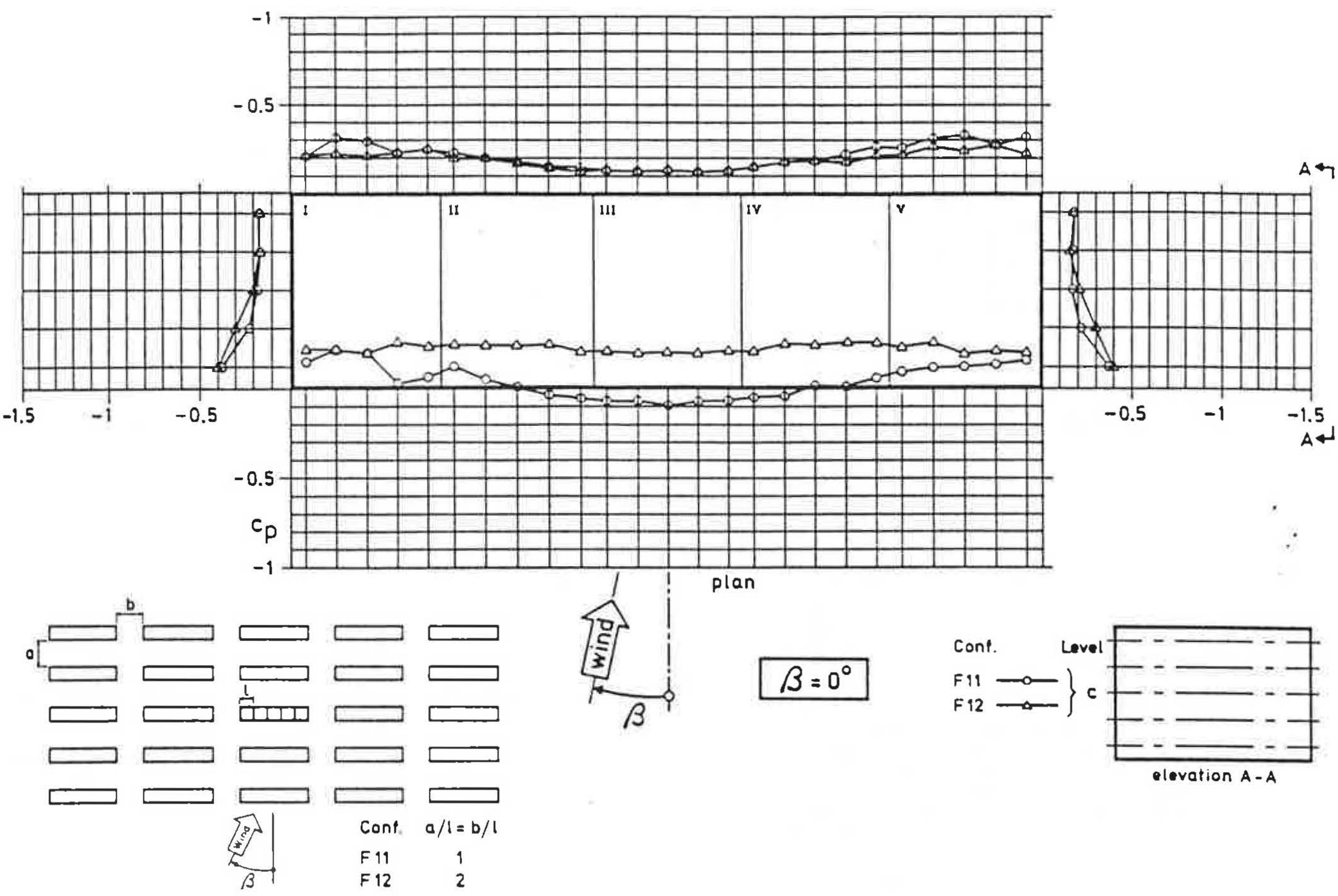


Fig.8 Cont´d

b. Wind angle β =60° and 90°



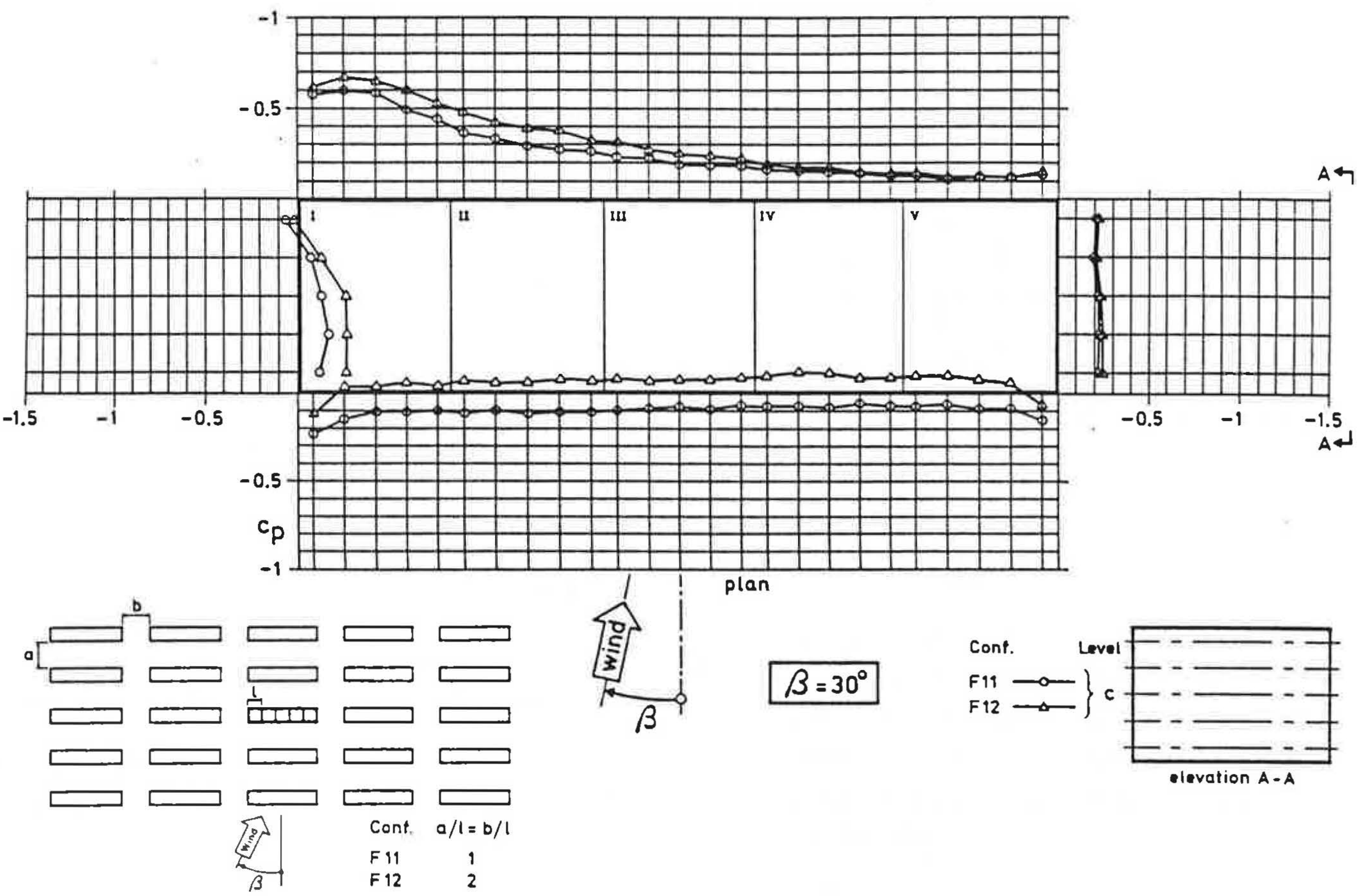
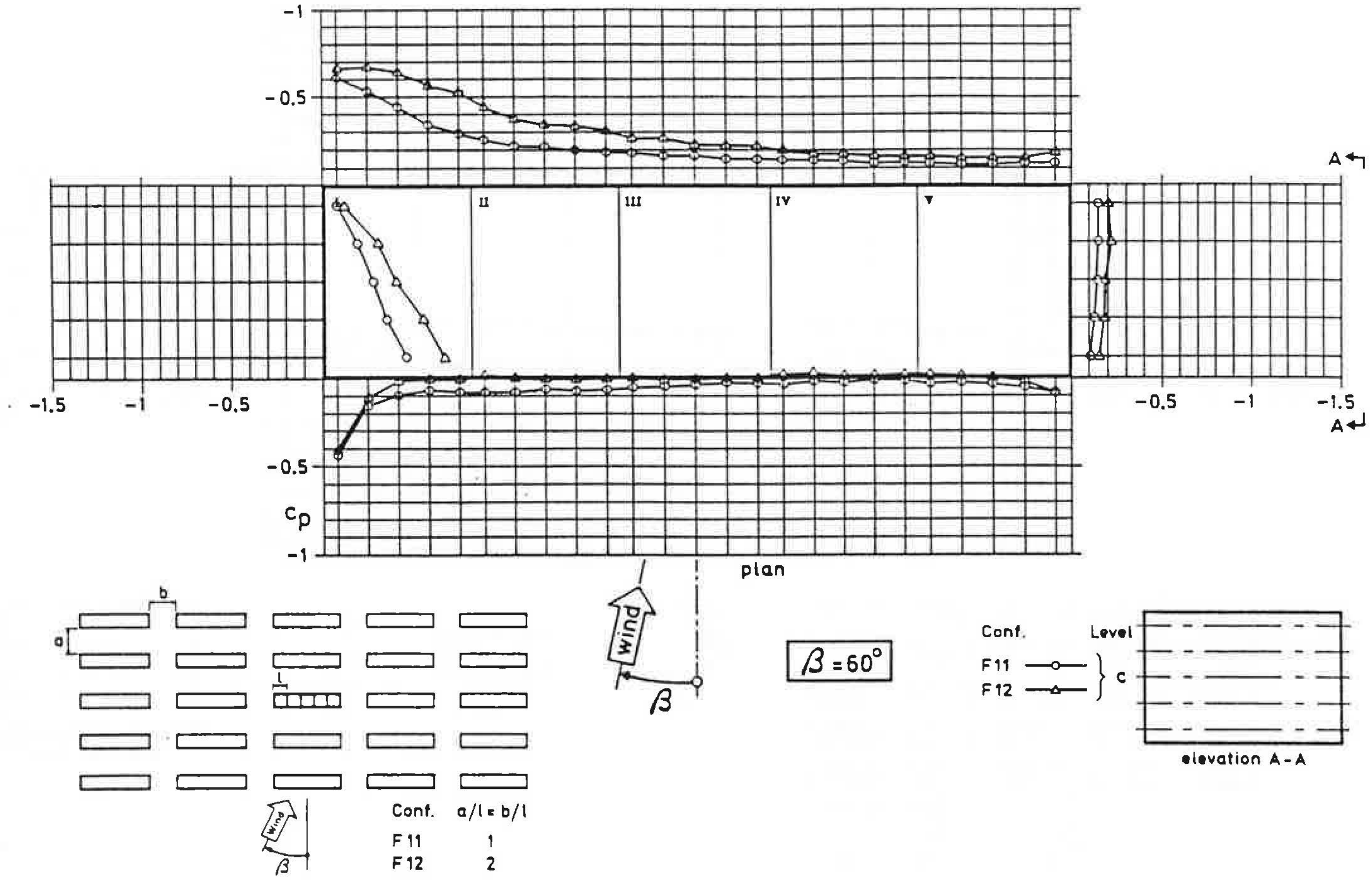


Fig.9 Mean-pressure distributions over the model walls.
Config´s F11 and F12

a. Wind angle $\beta = 0^{\circ}$ and 30°



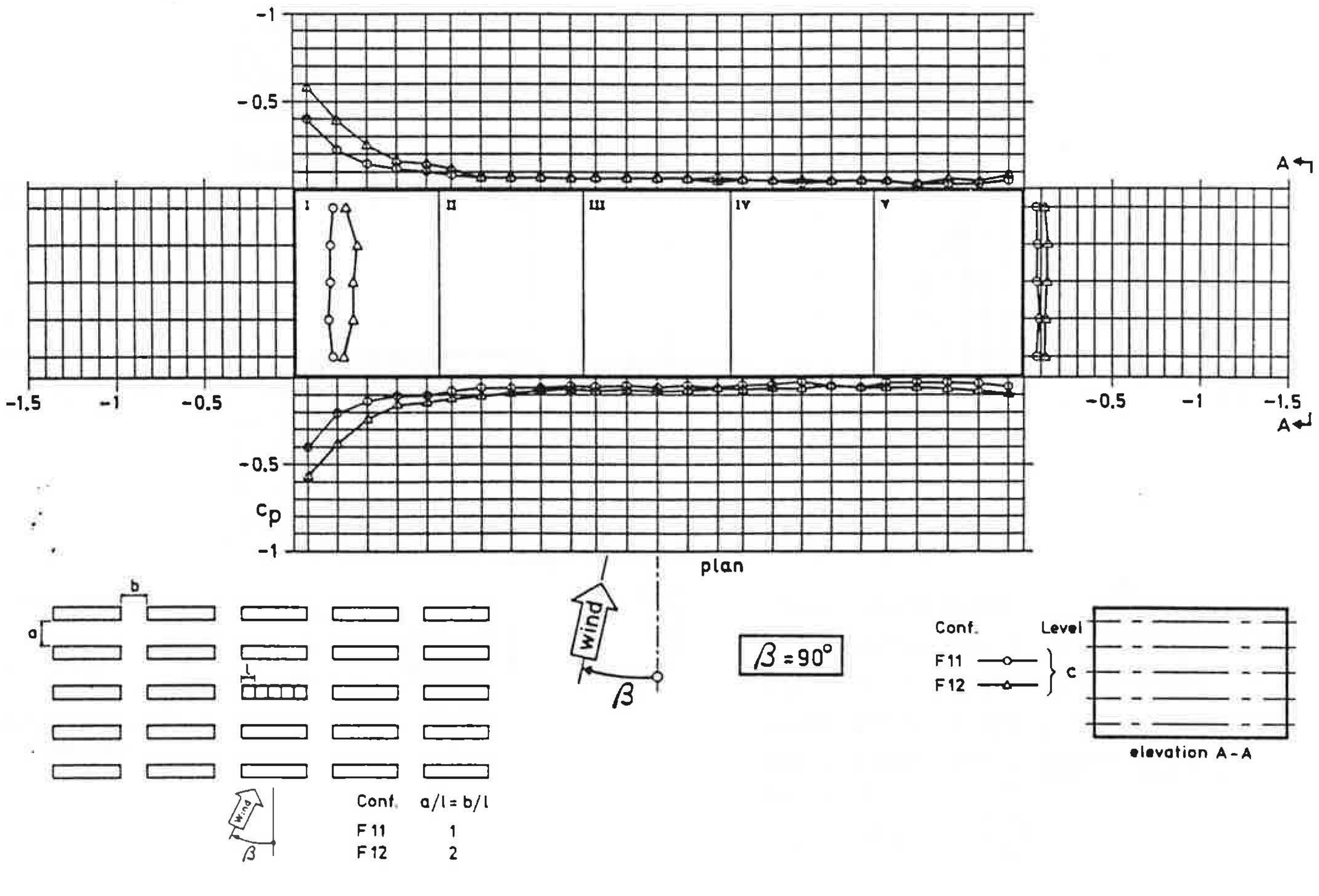
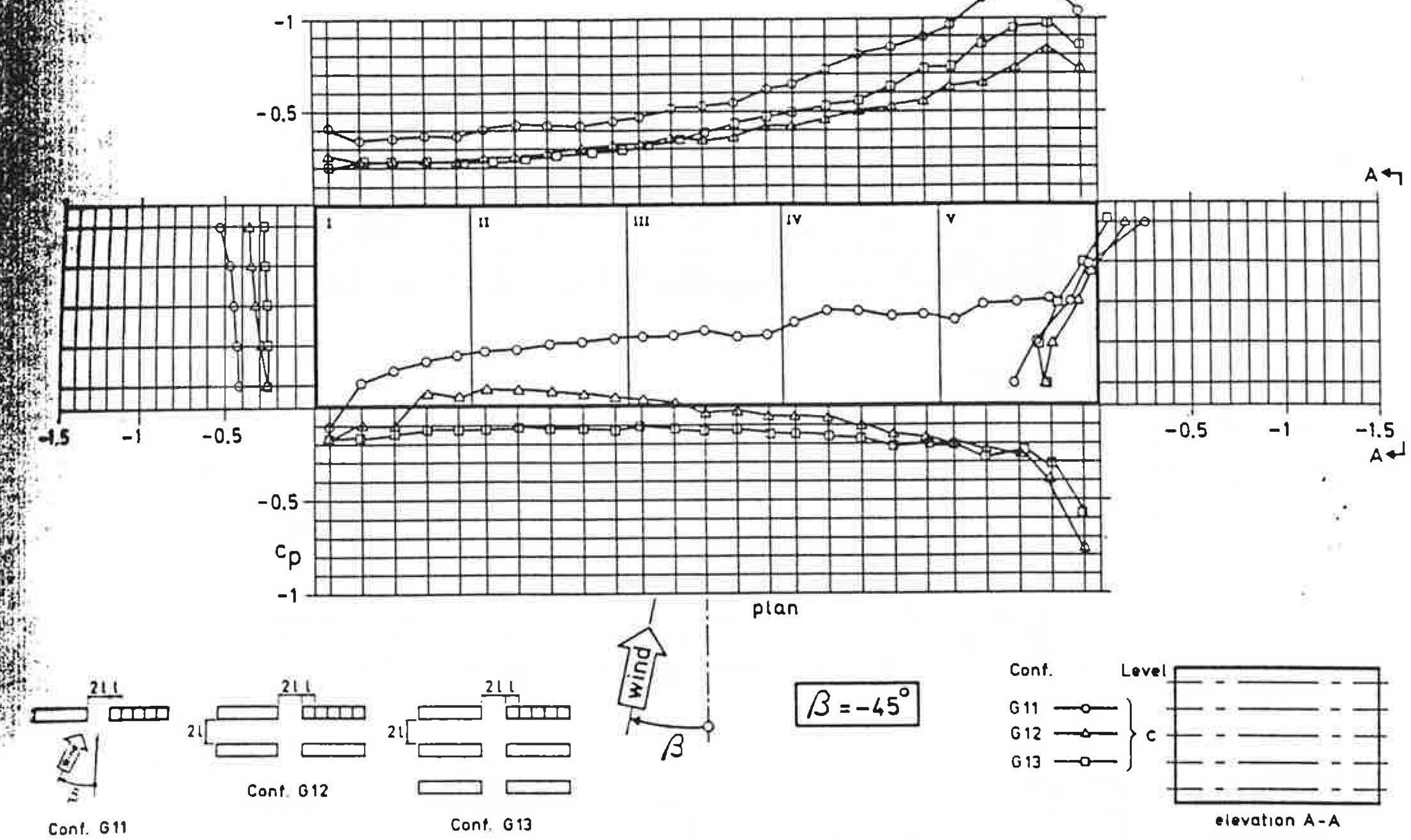


Fig.9 Cont´d

b. Wind angle $\beta = 60^\circ$ and 90°



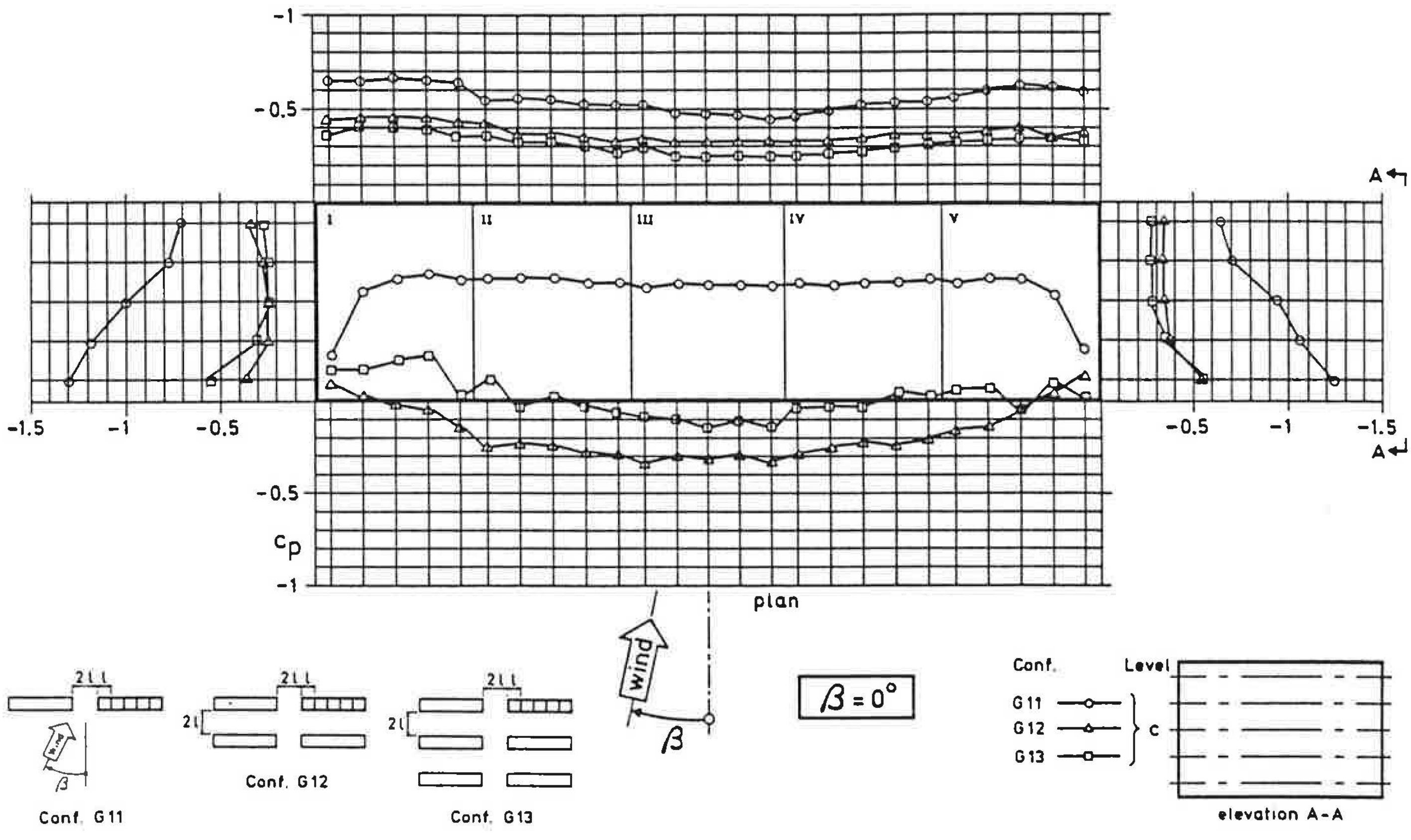


Fig.10 Mean-pressure distributions over the model walls. Config´s G11-G13

a. Wind angle $\beta = -45^{\circ}$ and 0°

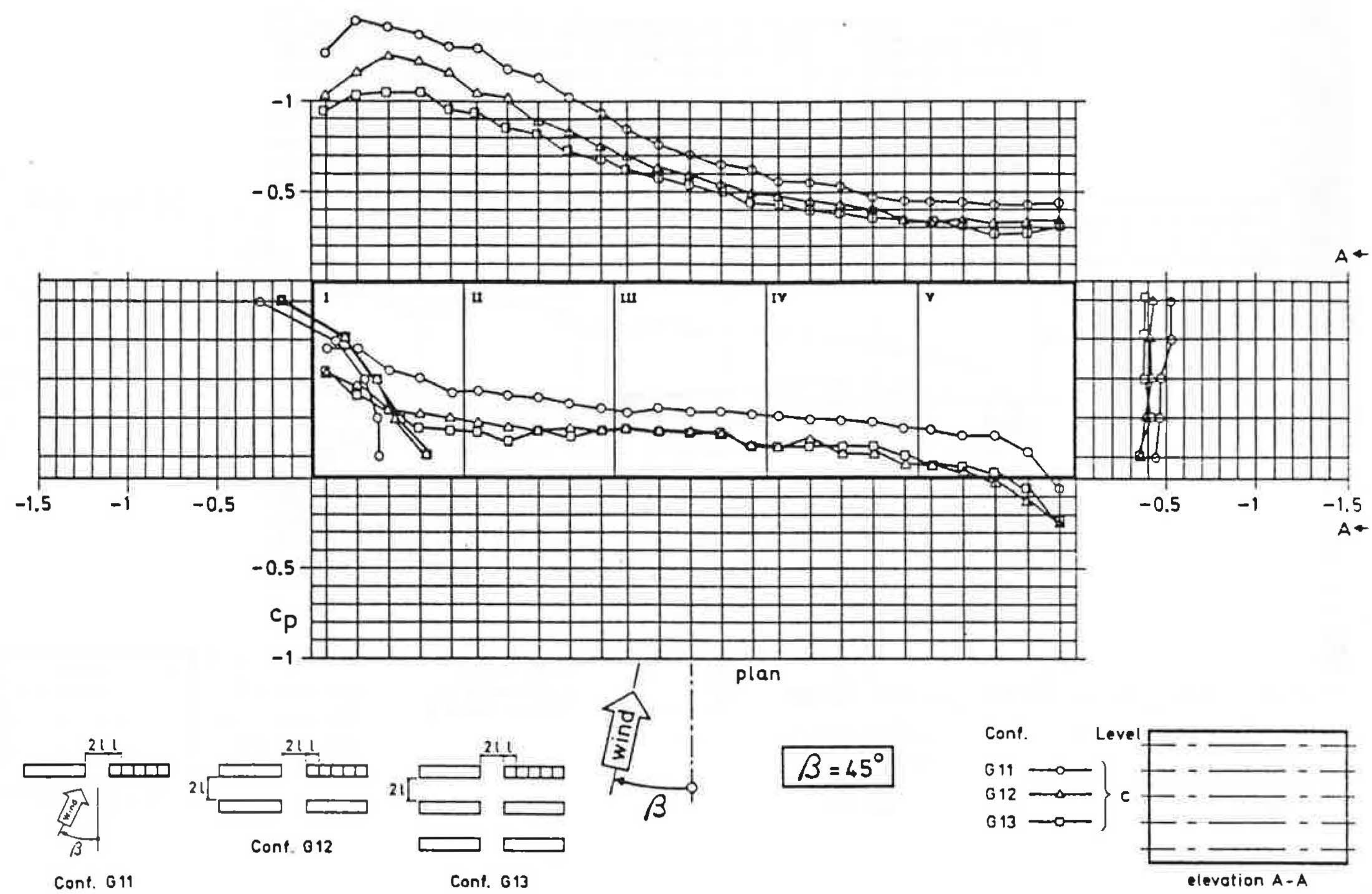


Fig.10 Cont´d

b. Wind angle β =45°

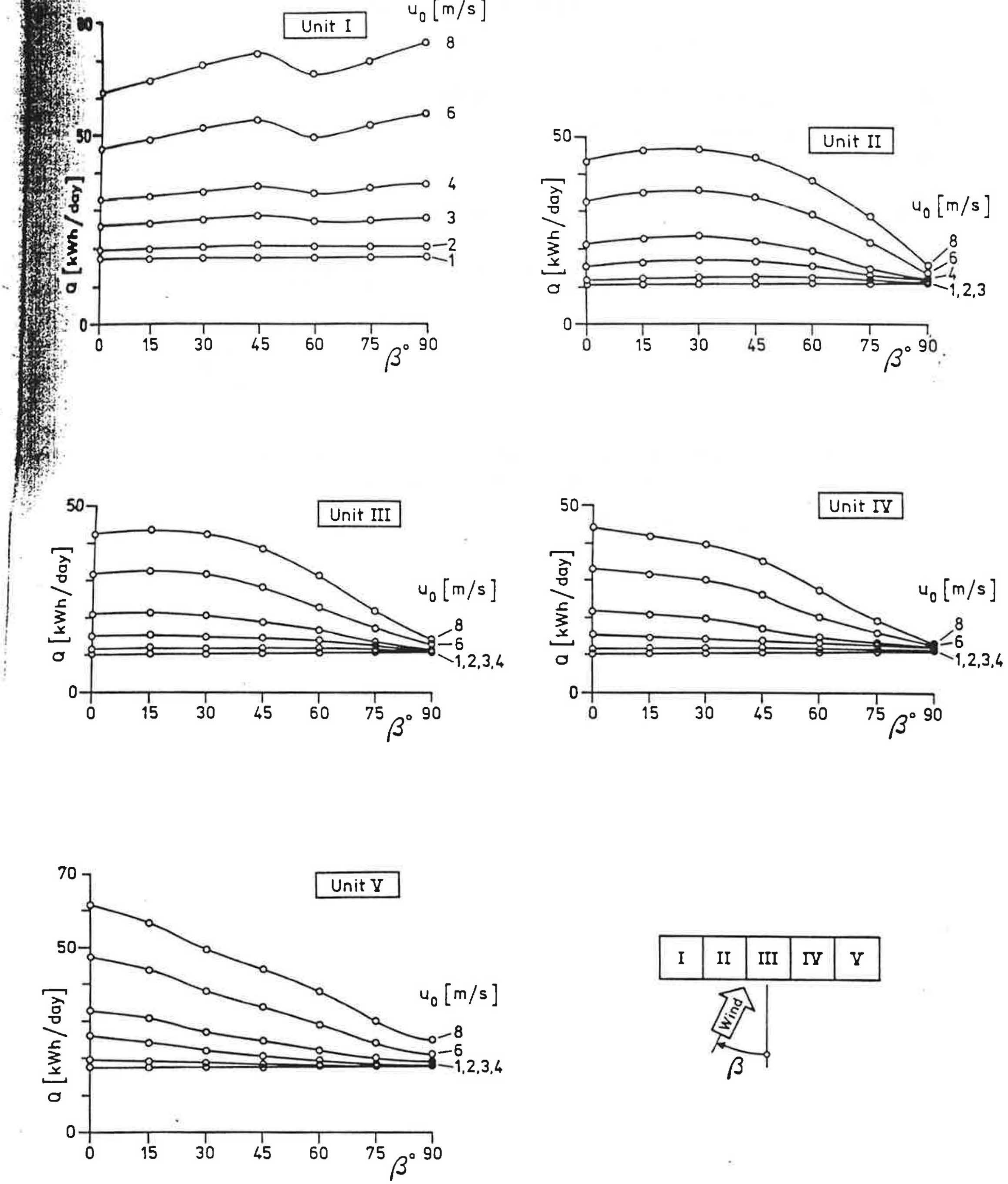


Fig.11 Influence of wind direction and wind speed on the ventilation loss from an isolated row of houses (model configuration A10) at $\Delta T = 20^{\circ}C$

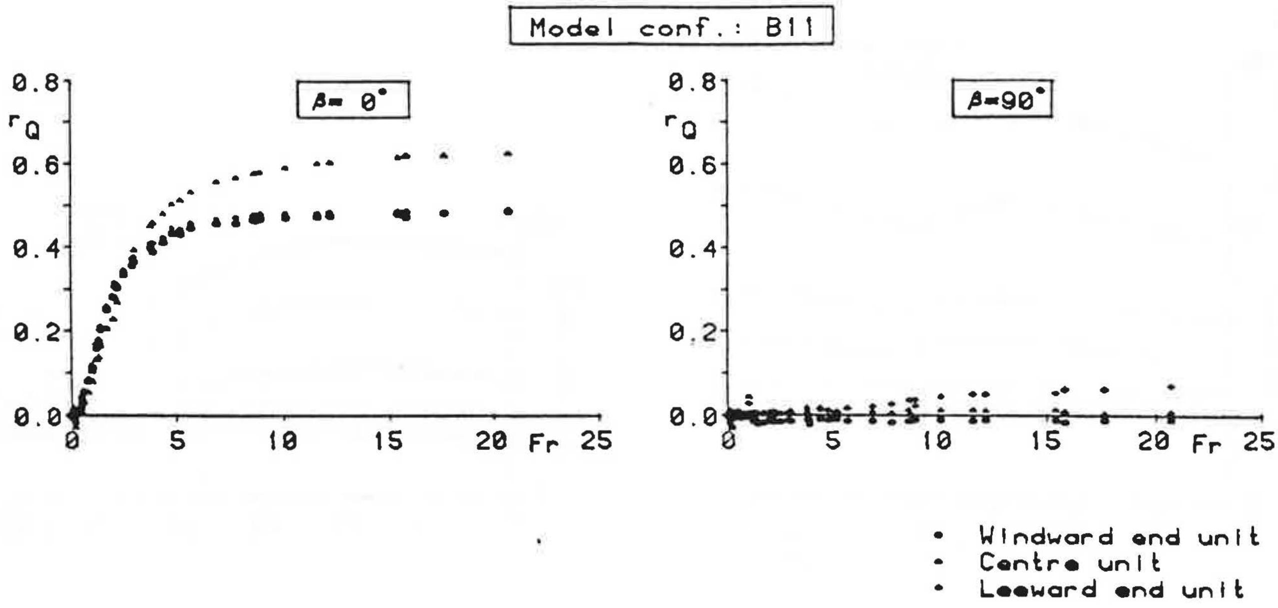


Fig.12 Normalized heat loss reduction, r_Q, for the test house vs Froude number, Fr, and wind angle, β

a. Model config. B11

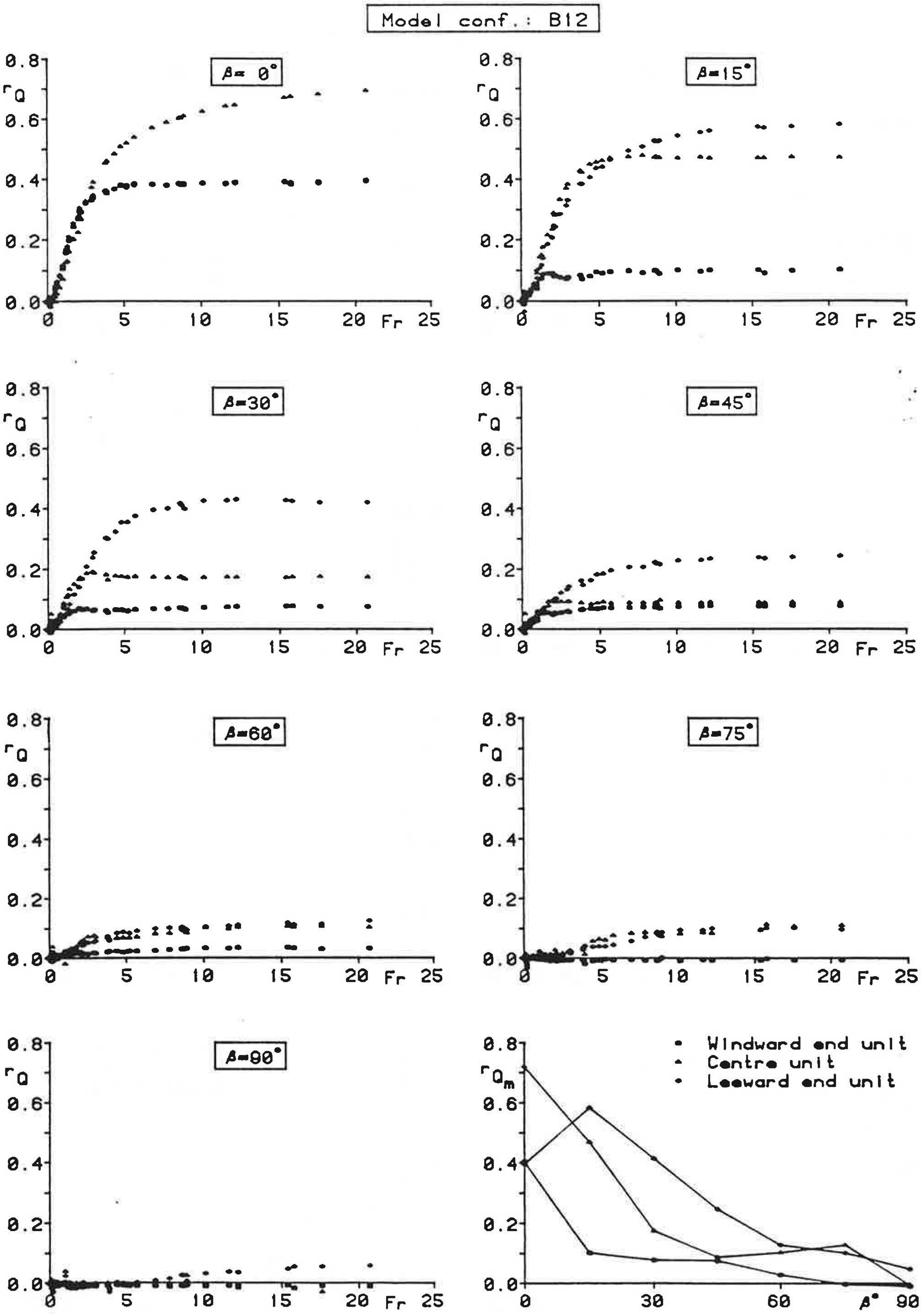


Fig.12 Cont´d

b. Model config. B12

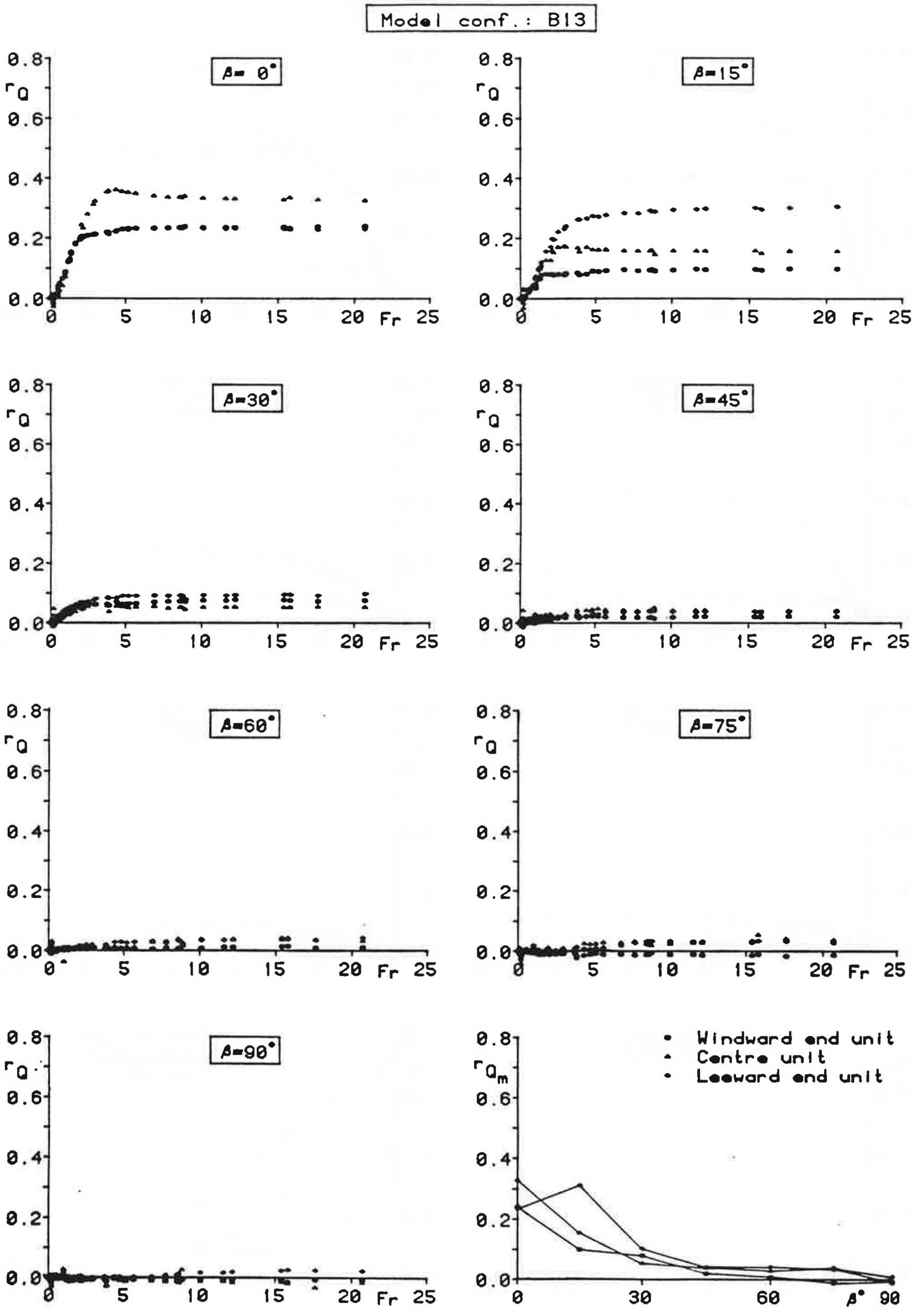


Fig.12 Cont´d

c. Model config. B13

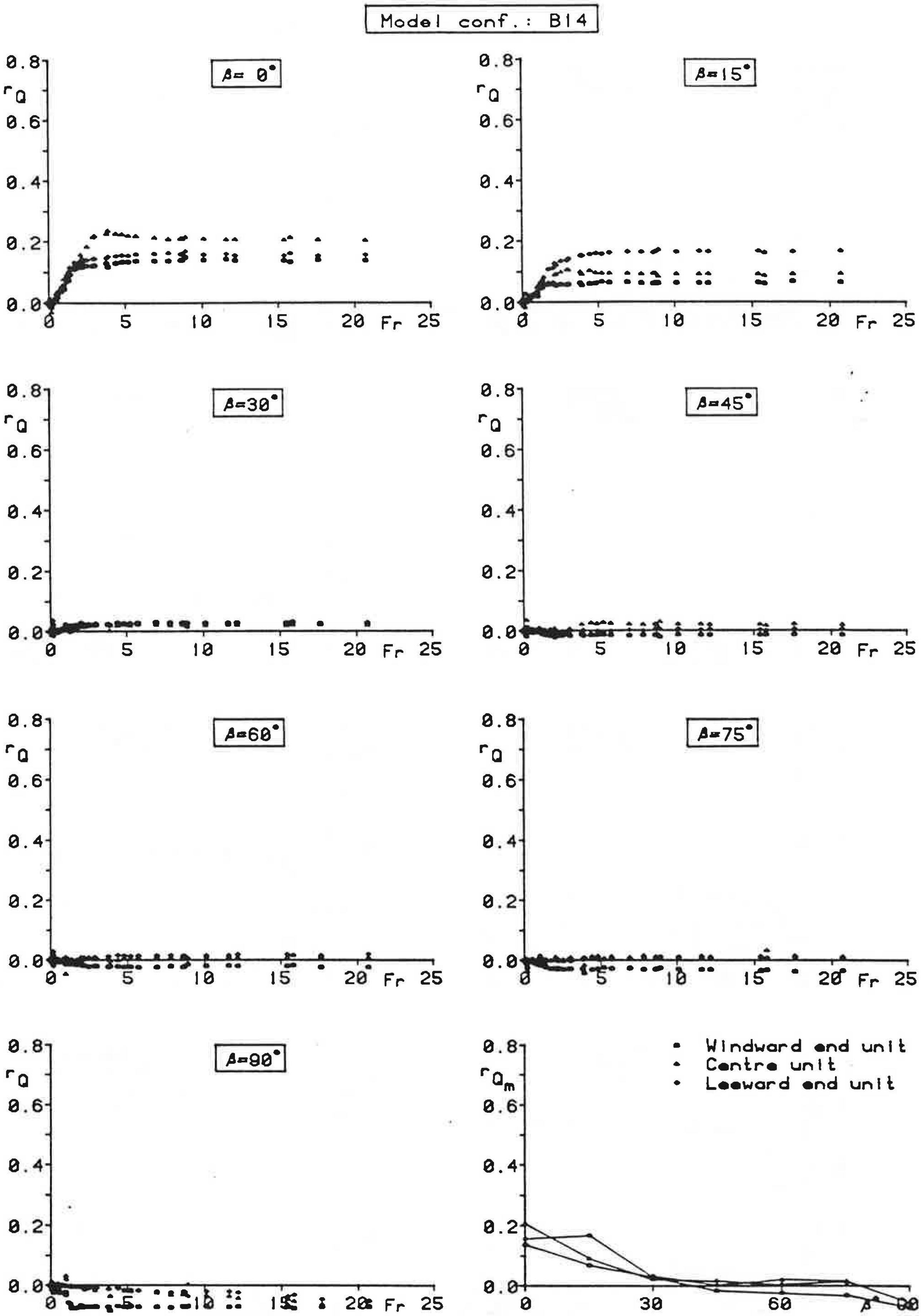


Fig.12 Cont´d

d. Model config. B14

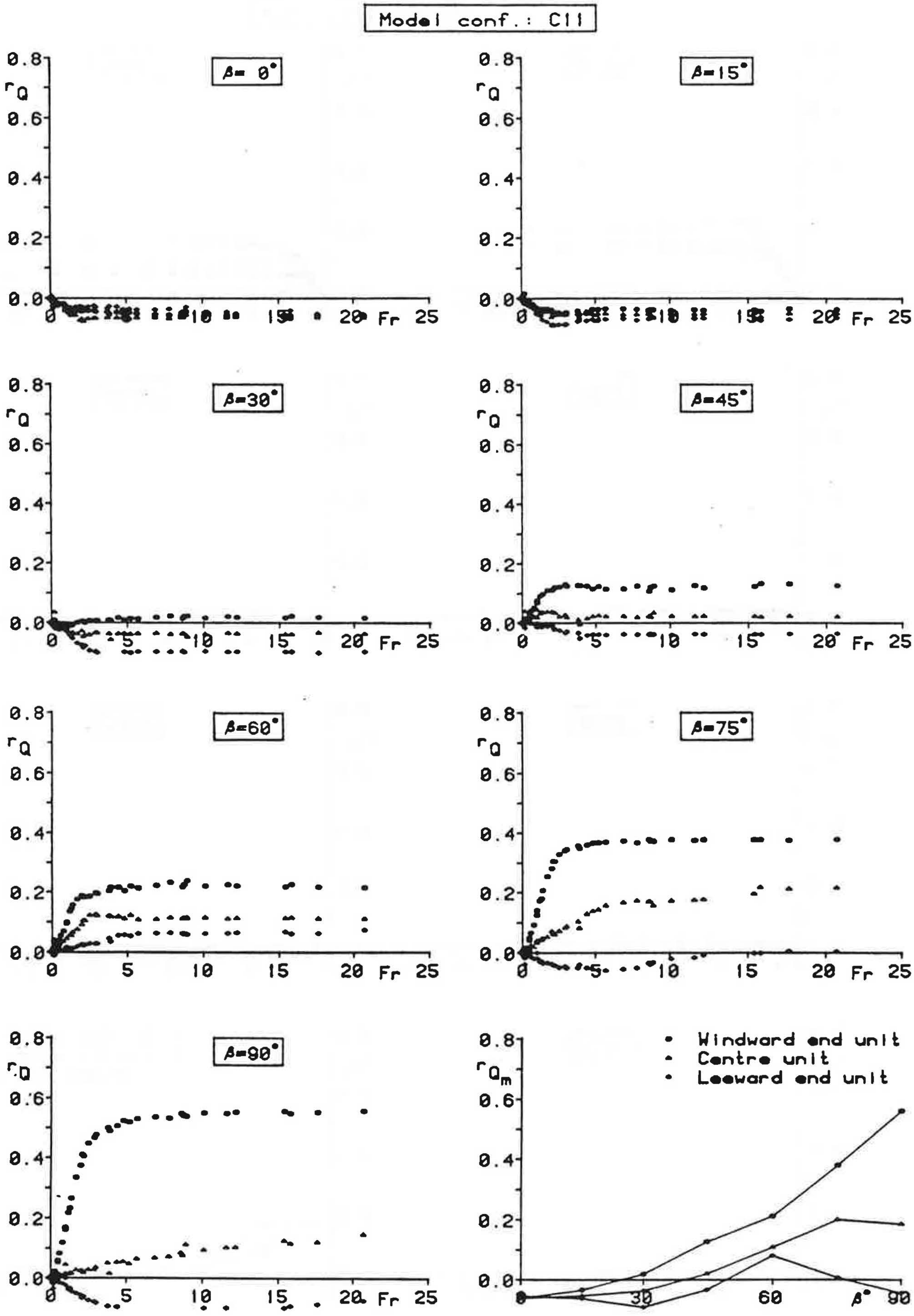


Fig.12 Cont´d

e. Model config. C11

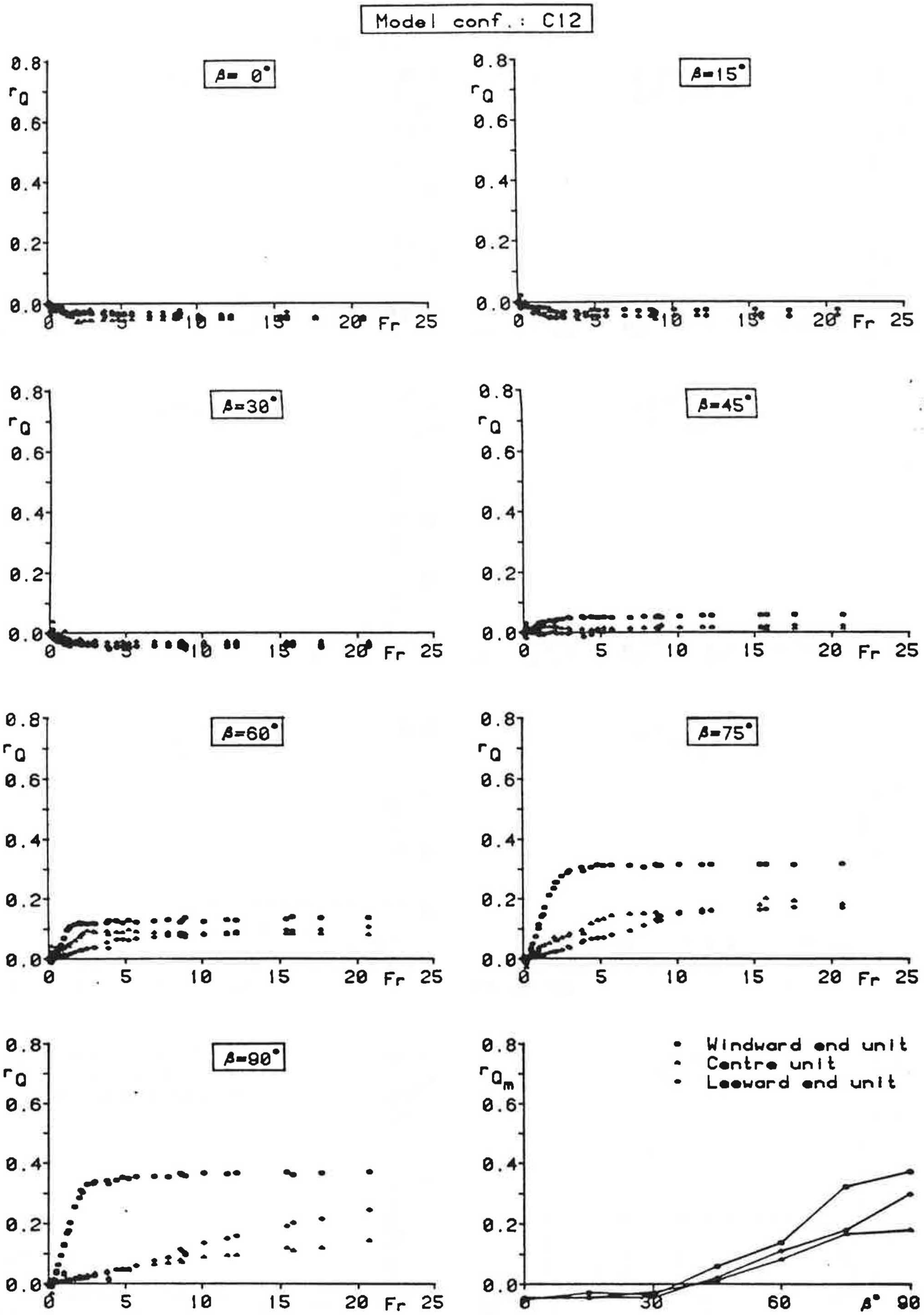


Fig.12 Cont´d

f. Model config. C12

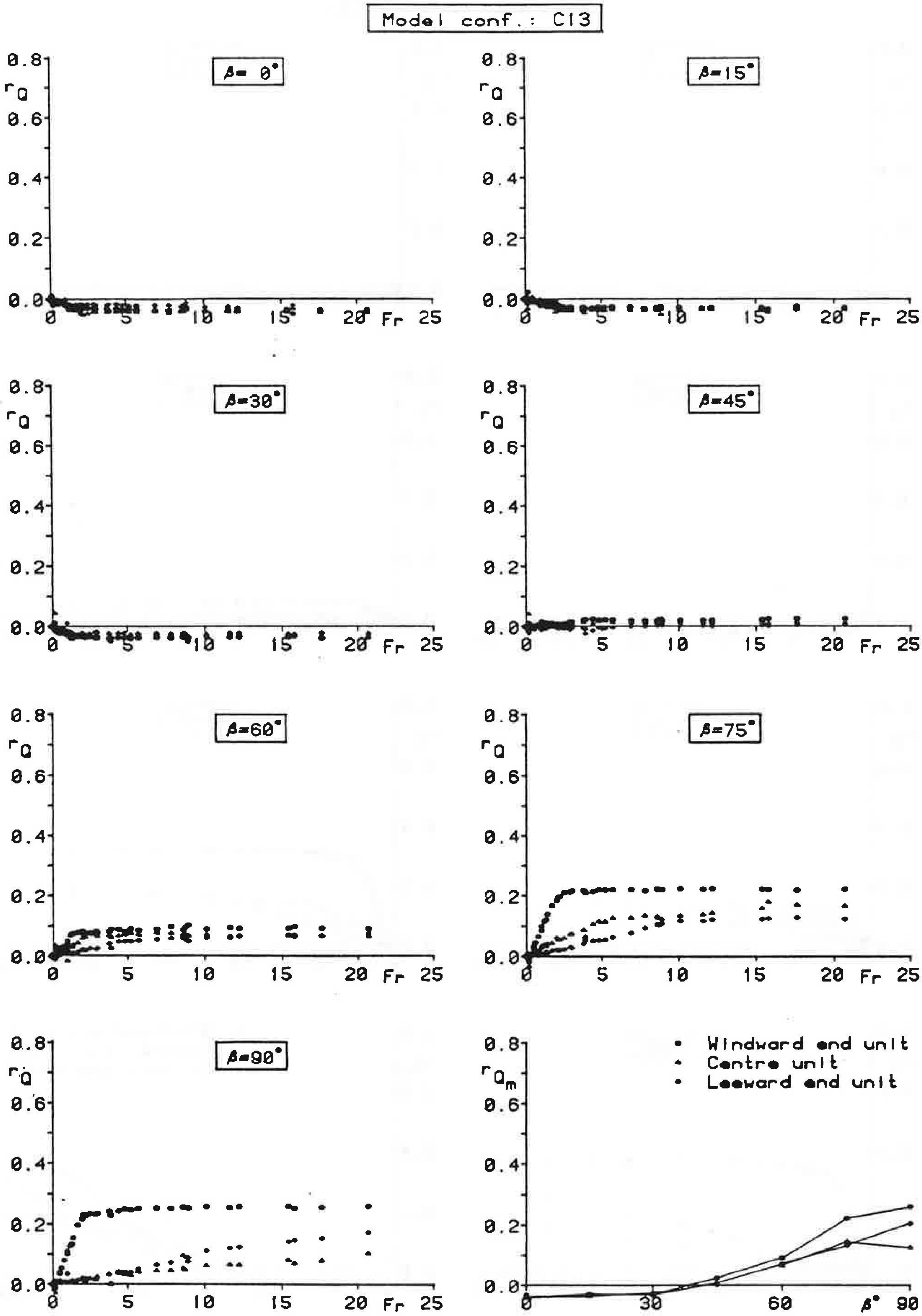


Fig.12 Cont´d

g. Model config. C13

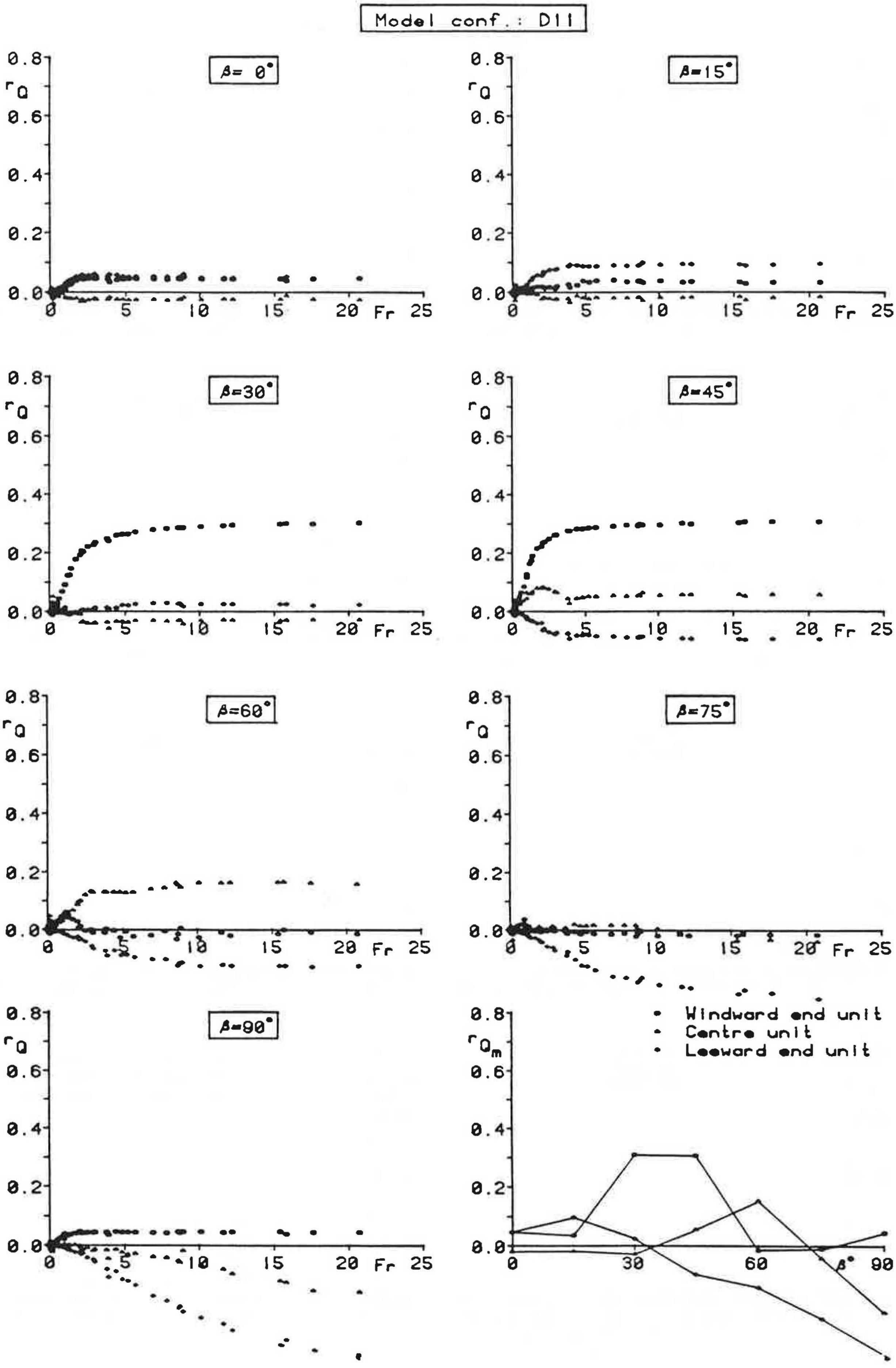


Fig.12 Cont´d

h. Model config. D11

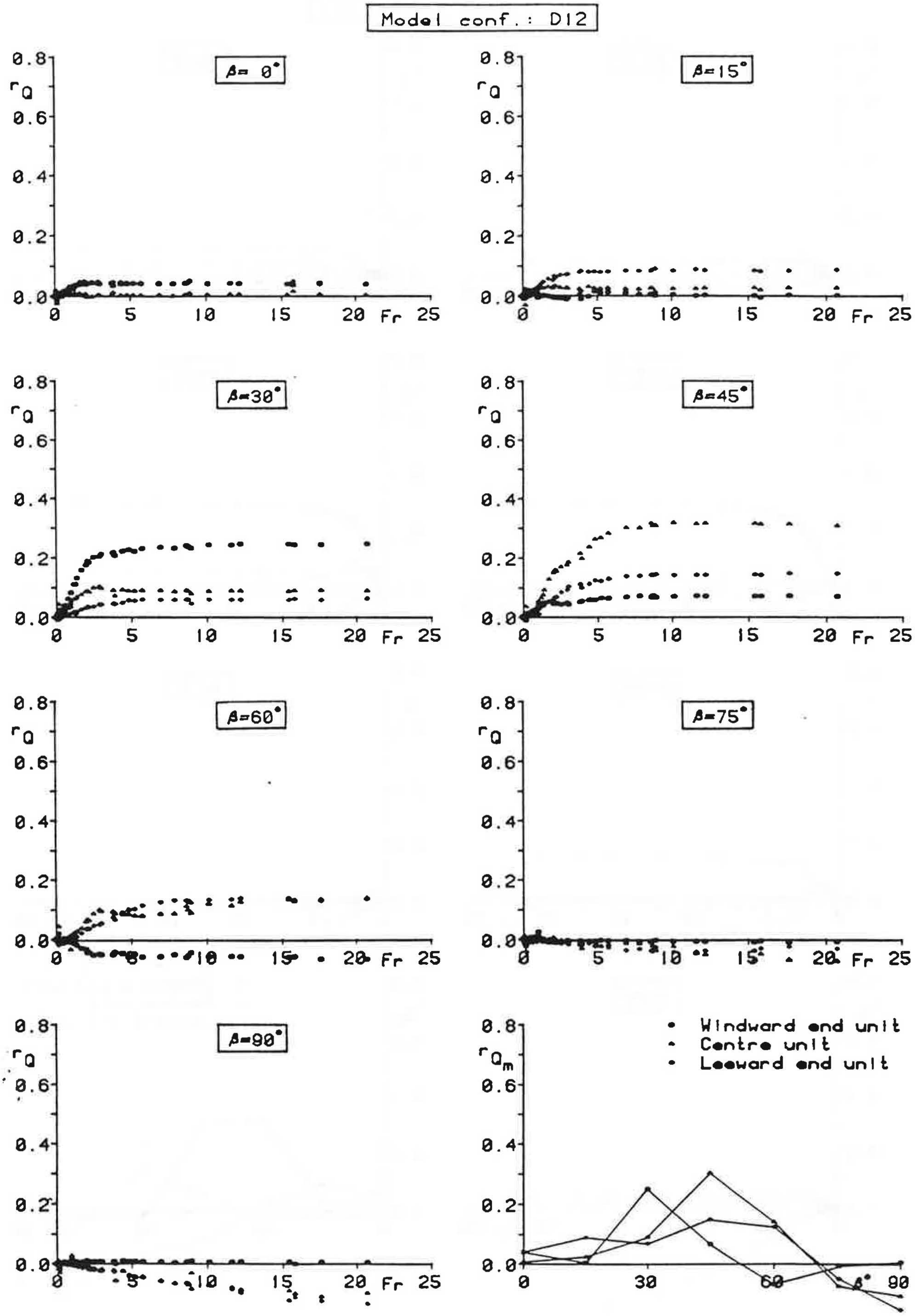


Fig.12 Cont´d

i. Model config. D12

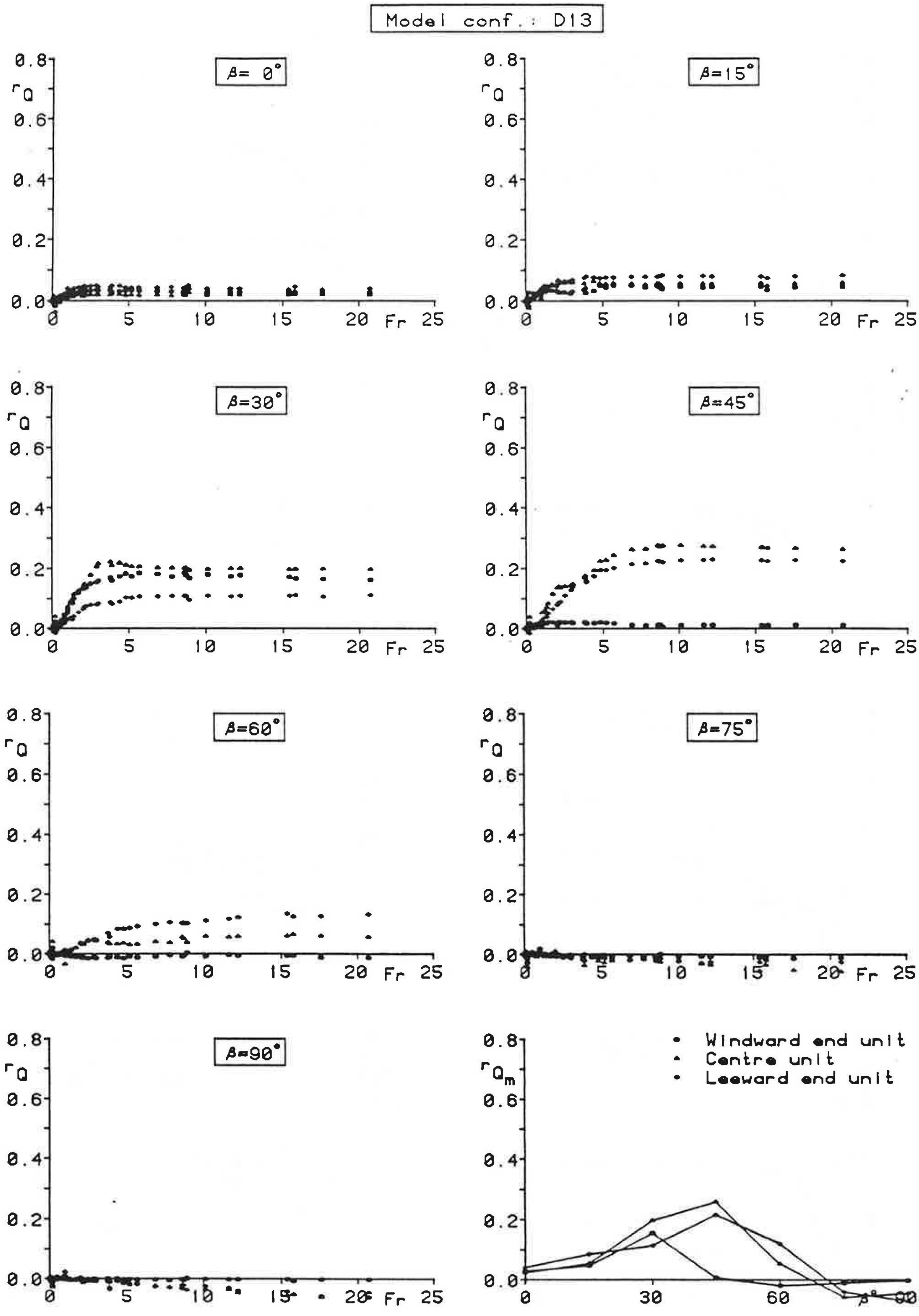


Fig.12 Cont´d

j. Model config. D13

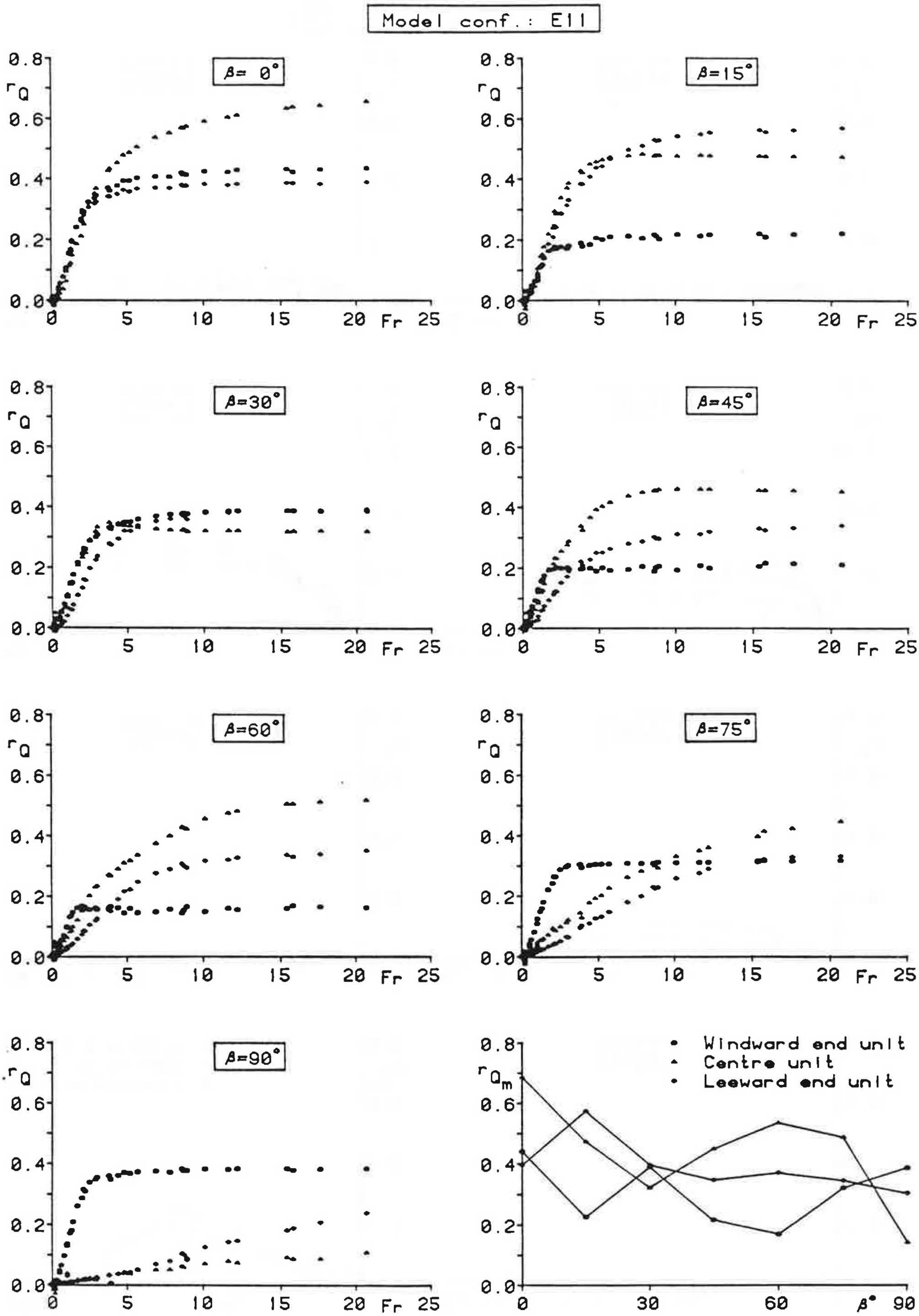


Fig.12 Cont´d

k. Model config. E11

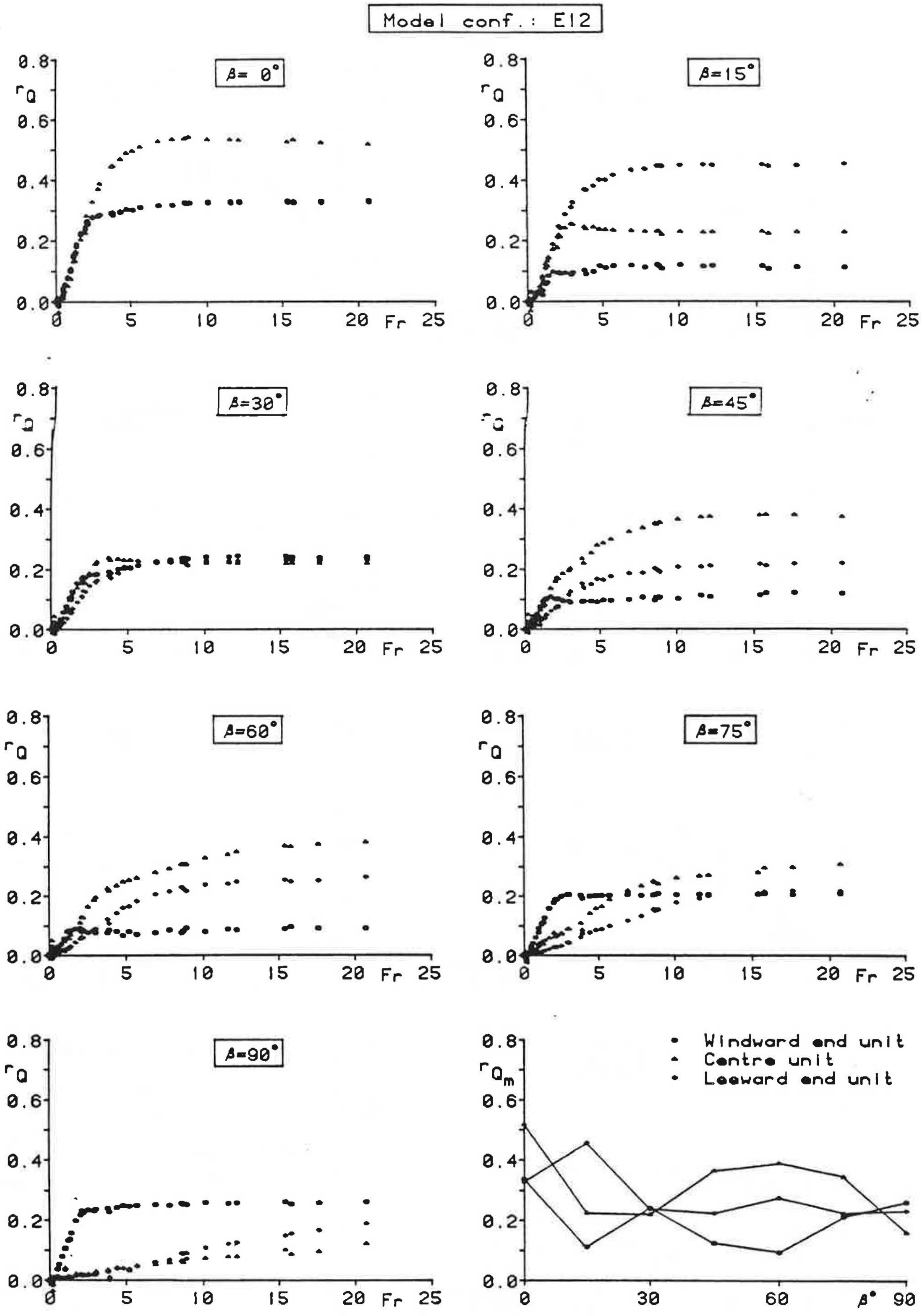


Fig.12 Cont´d

1. Model config. E12

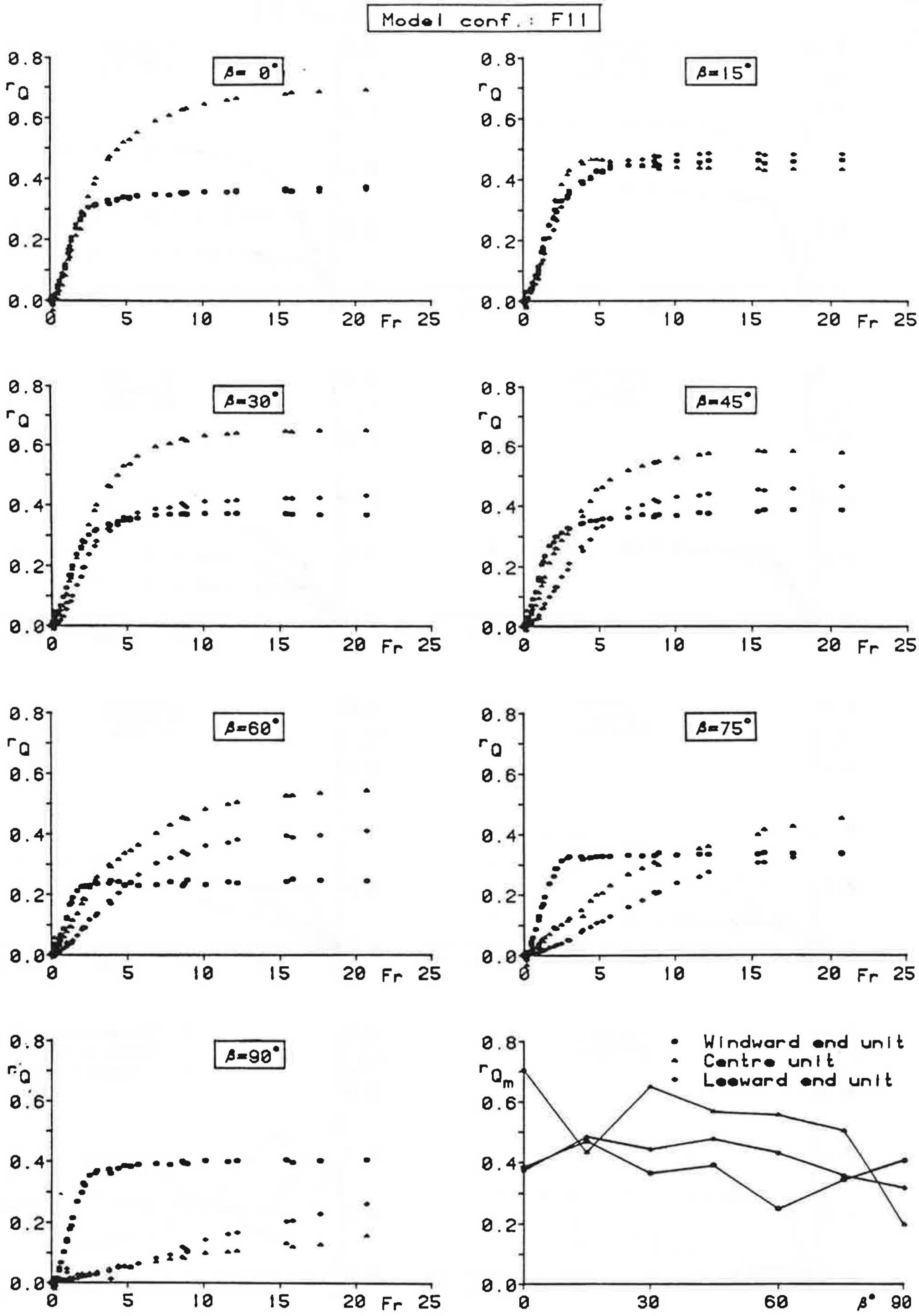


Fig.12 Cont´d

m. Model config. F11

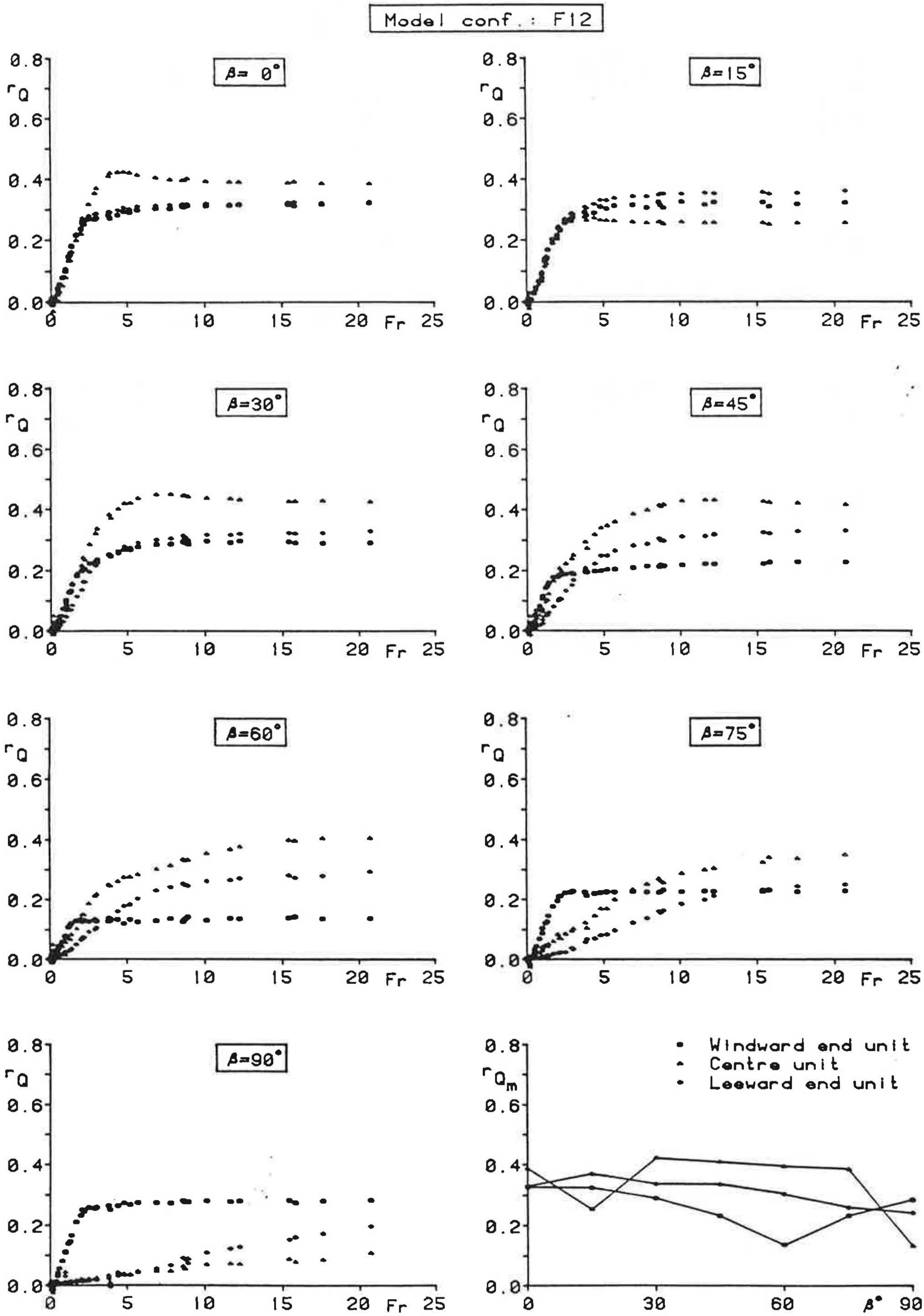


Fig.12 Cont´d

n. Model config. F12

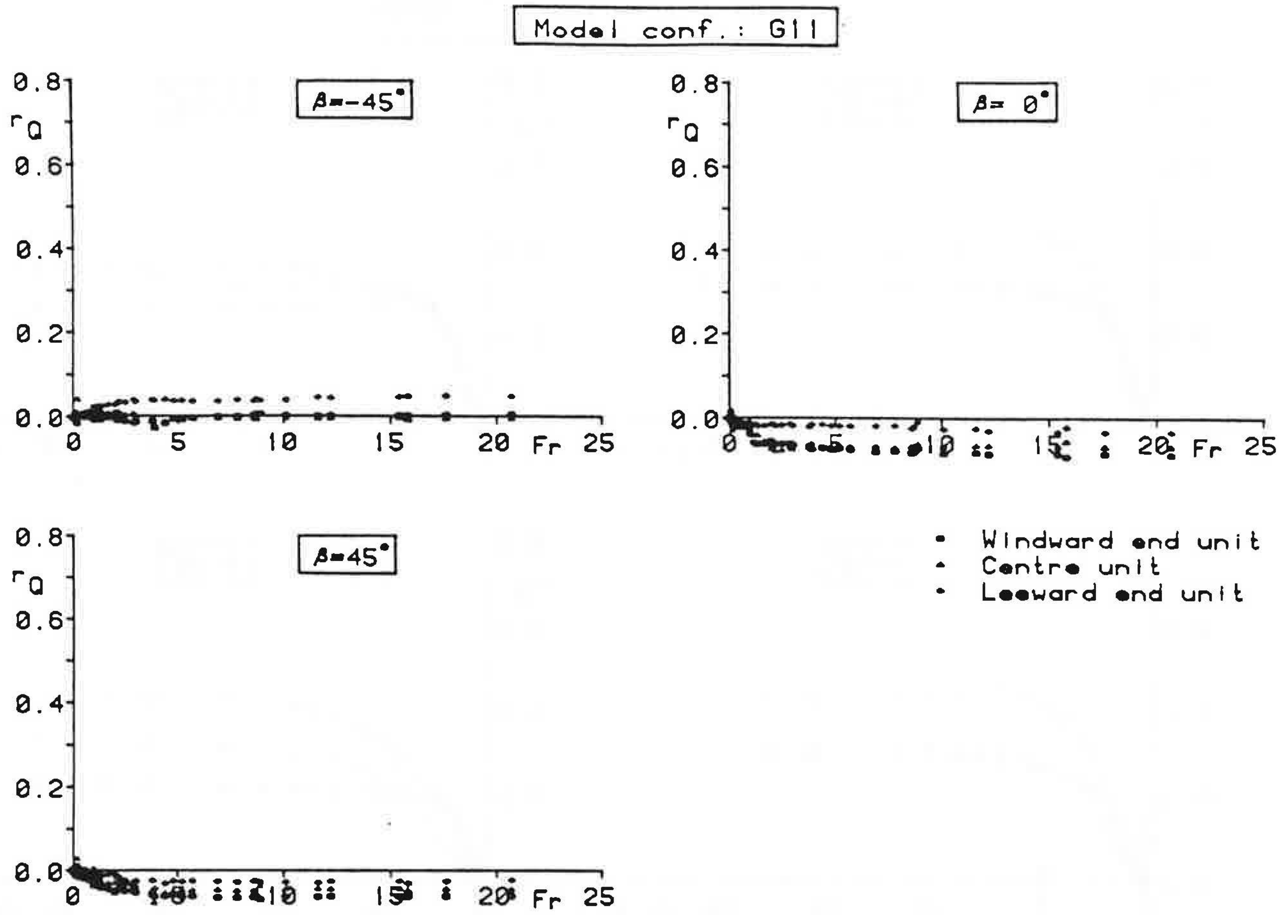


Fig.12 Cont´d

o. Model config. G11

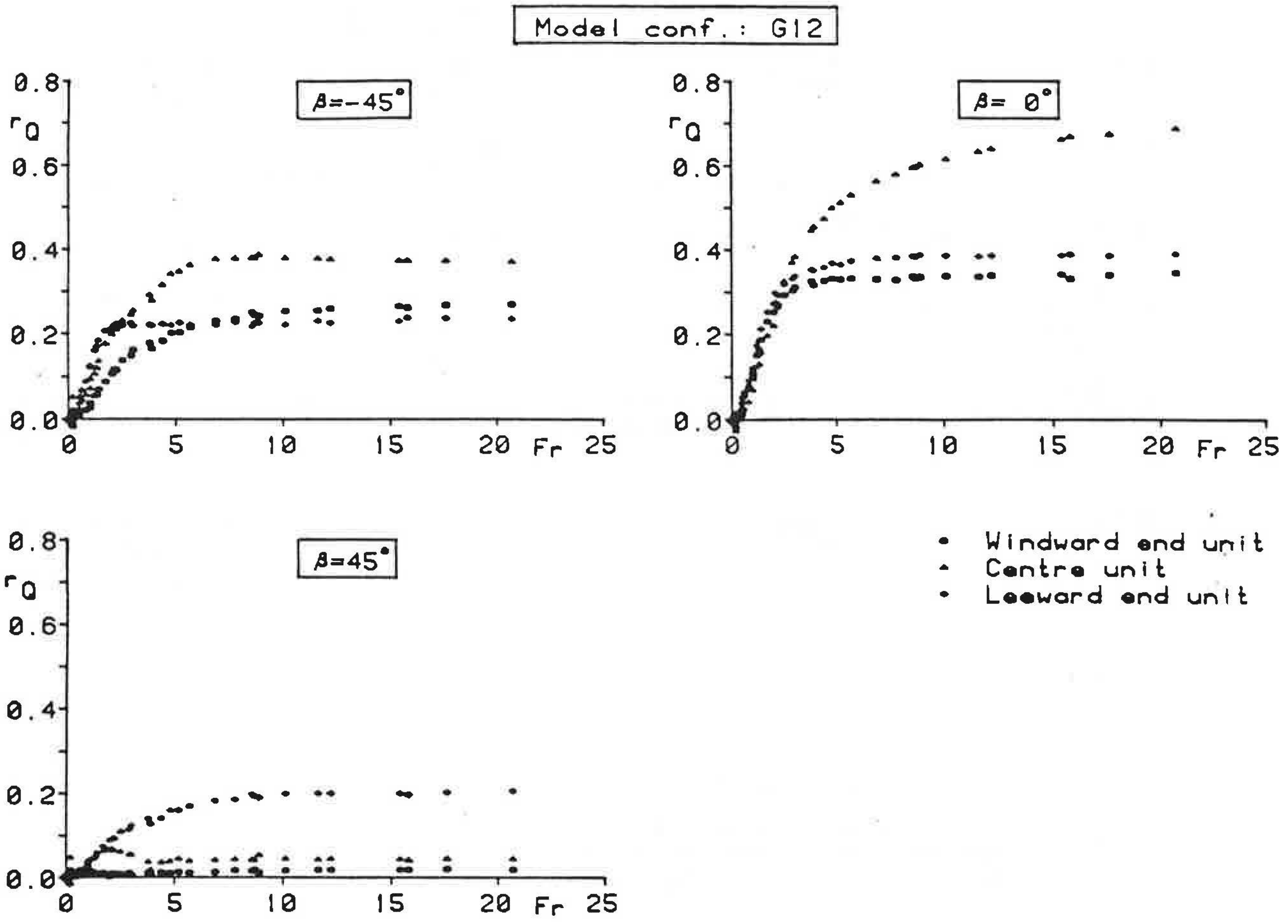


Fig.12 Cont´d

p. Model config. G12

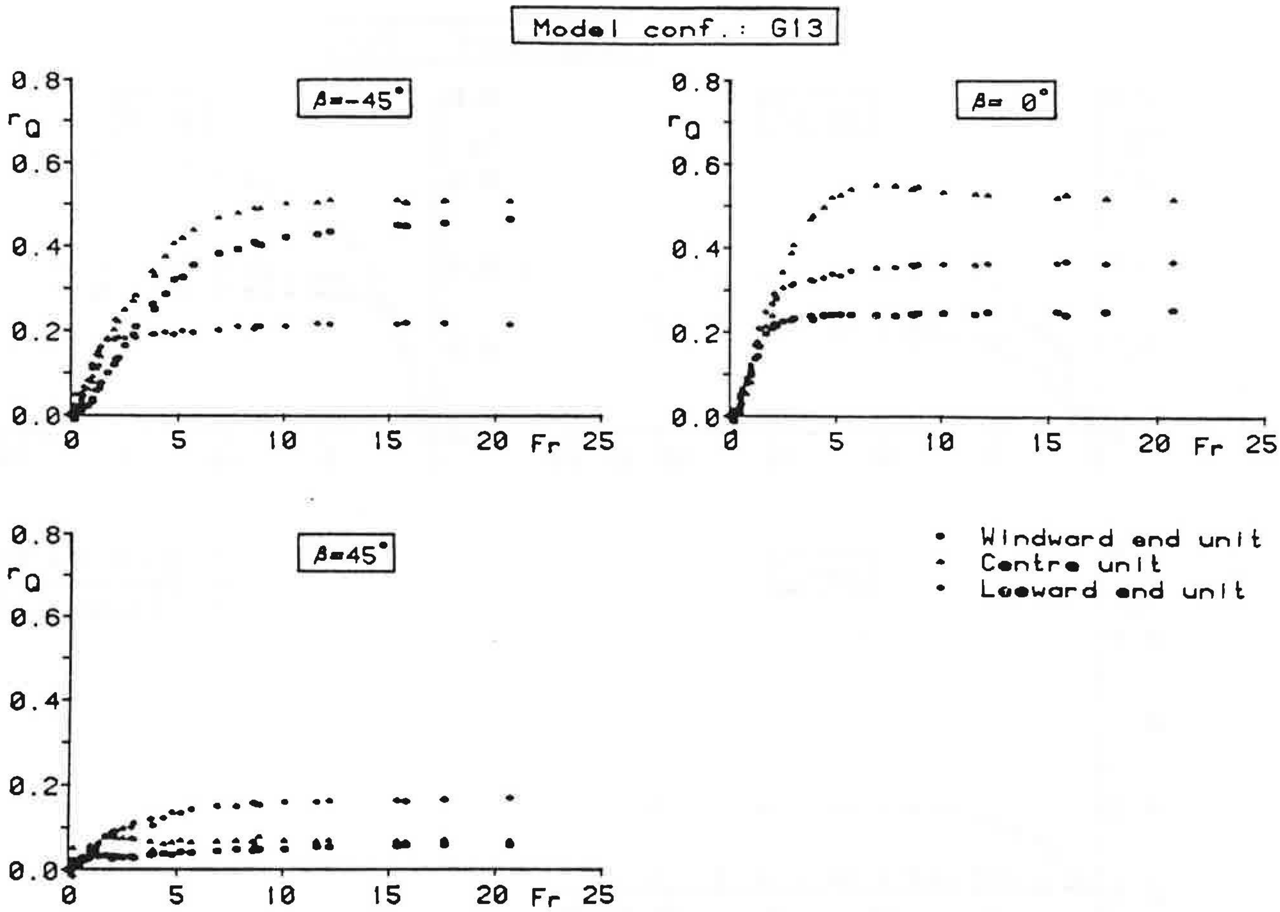


Fig.12 Cont´d

g. Model config. G13