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THE DESIGN AND TESTING OF A LOUVRED BLAST RELIEF SYSTEM

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ABSTRACT

The use of hinged louvres for the relief of explosion overpressures has two clear advantages. Natural ventilation will occur at all times reducing the incidence of a flammable gas cloud and venting between the louvres will release pressure even before the louvre opens.

This paper describes the complete system and the methods used to predict the opening pressures and times.

Explosion tests which were performed by ABB at TNO are described. The main results of the tests are presented. Pressure measurements were taken inside the test compartment, between the vanes of the louvre panel and outside the compartment. It was found that the dynamic pressure (drag) affected the opening of the louvres. The blockage of the flow through the louvres and the effective driving pressure is discussed. The calibration of calculation methods used for performance prediction is described.

The louvred blast relief system is presently being incorporated into three major northern North Sea platforms.

1. INTRODUCTION

The purpose of blast relief systems is to play a part in maximising the inherent safety of the installation with respect to explosions. This usually takes the form of a reduction in peak overpressure long after the vent has opened.

The method used until now is the removal of as much as possible of the unburnt mixture to the outside of the compartment, as soon as possible, so that the work done against the external atmosphere is maximised. This usually has the effect of redistributing the energy release in a favourable way as far as the interior of the module is concerned. This may give a local immediate reduction in pressure on opening but this is incidental. The effectiveness is judged by the later consequences of the vent action.

The hinged relief louvre has the advantage of providing natural ventilation at all times and allows the passage of the inflammable mixture even before opening. This may be crucial if a less than extreme explosion is imminent.

The traditional specification for a blast relief panel is often in the form of a statement such as 'the panel must start to open at an overpressure of 50 mbar and be fully open within 50 milliseconds'.

The opening time 't_o' will depend on the pressure time history experienced at the panel, in particular the rate of increase of pressure 'K' shortly after the time of opening. A specification in this limited form is hence ambiguous. The sensitivity study performed in the preparation of this paper in fact shows that, at least for lightweight solid relief panels, the opening time criterion is a good measure of vent effectiveness.

ABB Environmental have developed a hinged louvre design which satisfies the additional design constraints given in Table 1, maximises natural ventilation and gives smooth pressure relief even before opening occurs.

A description of the system is given in the following section. The verification testing of the louvre panel at TNO in Holland is described in Section 3.

As the pressure time histories obtained during the tests will not correspond to those which may be experienced by the installed system, a process of verification was needed after the tests were performed. This was achieved by the construction and calibration of a theoretical model of the hinged louvre using the test results. This model was then used to predict expected behaviour under a number of realistic loading time histories. The theoretical model is described in Section 4.

2. DESCRIPTION OF THE SYSTEM

The panel frame and louvre vanes are constructed of sea water resistant aluminium. A general arrangement for the blast relieving louvre system is shown in Figure 1. This relief louvre will form part of walls which may include fixed panels, relief panels, fixed louvres, doors, penetrations and frames. The overall dimensions of the panel are typically 1m high by 2m wide.

The panel consists of an inner and outer rigid frame. The inner frame is spanned vertically by a set of profiled louvre vanes welded to the inner frame and braced diagonally. The part of the louvre within the inner frame is hinged at 130mm from the lower end by a cylindrical bearing allowing rotation between 0° and 90°.

The top edge of the inner part of the panel is held in place by a thin aluminium plate or 'tongue' which runs along a groove on the outer frame top member. During panel release this tongue deforms plastically in such a way that the distance of the tip from the axis of rotation reduces leaving the panel free to rotate. These features of the design have been patented and form the basis of the release mechanism and hinge.

3. TESTING OF THE LOUVRE RELIEF SYSTEM

The relief louvre was tested at the $35m^3$ explosion testing facility at the Prins Maurits Laboratory which is part of the TNO organisation situated at Rijswijk in the Netherlands. The general layout of the facility showing the pressure transducer positions and the compartment geometry is given in Figure 2. The inset to the figure shows the positions of the transducers used for determination of the pressure time histories local to the louvre.

Pressure time histories within the compartment with peak values of 25 kN/m^2 (250 mbar) were generated by the ignition of a stoichiometric mixture of methane and air which filled the compartment. The adjustable secondary vent area was found to be partially blocked by an external explosion.

The tests were performed in three stages:-

1. Reference shots were generated with a minimum peak pressure of 25 kN/m^2 to establish the repeatability of the pressure time history.

2. A 'fixed louvre' shot was performed to measure the effective blockage ratio of the louvre at extreme gas mixture velocities and to obtain information on the pressure gradient (and inferred flow velocities) between 50 and 250 mbar. This gave information on the driving pressure under these conditions. These tests had three major advantages over previously performed wind tunnel tests. Firstly a gas/fuel mixture was expelled through the louvre, secondly the flow was time dependent with realistic flow velocities and thirdly the direction of flow through the louvre was represented.

   The results of these tests were used to fine tune the opening mechanism by comparison of the performance with a full structural non-linear simulation using the NISA finite element computer program which was run in house by ABB.

   Comparison of the results for a fixed conventional natural ventilation louvre and a hinged relief louvre indicated that the relief louvre gives a noticeable reduction in peak pressure.

3. A verification test of the hinged relief louvre was performed. The opening mechanism was adjusted by optimising the top plate thickness and height to ensure opening at 50 mbar pressure in the compartment.

4. SUITABILITY OF DESIGN

The performance of the release mechanism and structural integrity of the panels was validated by the tests. The performance and acceptability of the design, however, was confirmed by a theoretical model. In particular the response and dynamic support loads during an explosion were derived analytically. The louvre panels are to be installed as part of the explosion mitigation/prevention system in a large process module for a Northern North Sea platform.

The first step was to identify some typical pressure time histories for the module. It is generally accepted that there is no simple method of calculating pressure time histories during a confined hydrocarbon explosion in the presence of obstacles and confinement and so a survey of available FLACS simulation results and published experimental results at large scale was made.

The load experienced by the vent will itself be affected by the response of the vent. A reduction in local pressure may result from the vent opening and for a small compartment the pressure may then decrease. The so called first pressure peak (P1) is associated with this effect[1]. For the situation considered here, however, it is assumed that the rate of volume generation within the module is such that the pressure continues to rise virtually uninterrupted. The benefit of the new vent area is felt later in a reduction of the final peak overpressure which will be associated with blockage of the vent by an external explosion (P2) or maximum burning within the module (P3). The reduction of this peak pressure is, after all, the ultimate objective.

A 'typical' pressure time history for an extreme event in a large congested offshore module is shown in Figure 3. The pressure curves SLP reviewed are smooth in the range of interest, which is above the release pressure P_r (say 50 mbar) and for about 50 milliseconds thereafter (see Figure 4). This applies even near the vent, although it could be argued that the FLACS code does not adequately represent the vent opening. A straight line may be fitted to the curve over this range. The slopes 'k' of typical time histories were found to lie in the range 2 bar/sec to 5 bar/sec. These slopes are considerably less than those which would be used for idealisation of the complete time history as a triangular pulse where rates of up to 18 bar/sec have been found.

The pressure time history over the relevant duration was represented by the simple linear relation:

$$P(t) = k\,t \qquad (1)$$

where k takes values in the range 200,000 N/m²/s to 500,000 N/m²/s (2 to 5 bar/s). The time origin is taken to give the correct relation between P and t at the release time 't_r' and thereafter. This may not correspond to the ignition time which is usually considerably earlier.

The slopes of the pressure time histories obtained during the tests were found to be within the desired range despite the small compartment size and relatively low peak overpressures.

The dynamic response of hinged explosion relief panels (ERP's) may be predicted following the approach given in the FABIG Technical Note[2] and illustrated in Figure 5.

For a downward hinging lightweight panel Newton's second law gives simply:

$$\frac{m\, b\, l^3}{3}\,\ddot{\theta} = \frac{b\, l^2}{2}\,\alpha\, P(t) + \frac{b\, l^2}{2}\, m\, g\, \sin(\theta) \qquad (2)$$

where $\ddot{\theta}$ is the panel angular acceleration (radians/s^2)
l is the panel radial length (m)
m is the mass of the panel per square metre (kg/m^2)
b is the breadth of the panel (m)
θ is the opening angle from the vertical
g is the acceleration due to gravity (9.81 m/s^2)
$P(t)$ is the pressure at time t in seconds (N/m^2)
and α is a factor used to take account of the restraining pressure P_s.

The restraining pressure 'P_s' represents the restraining effect of drag on the unloaded side of the panel, an external pressure build up due to confinement outside the vent or an external explosion.

i.e. For a solid panel

$$\alpha(t)\, P(t) = P(t) - P_s(t) \qquad (3)$$

In the case of a hinged louvre panel α may represent the proportion of the pressure P which is experienced by the panel as a driving pressure for the opening. This factor will depend on the velocity of flow through the louvre, the velocity of the louvre, the local gas mixture flow velocity and the instantaneous angle of attack of the flow. In this context it may be associated with the blockage factor obtained from wind tunnel or (preferably) explosion tests.

The tests indicate an initial blockage factor of 0.58. This blockage was expected to increase with flow velocity through the louvre at increasing Reynold's number. In fact, there was a decrease at the highest flow velocities. This has implications for the release mechanism which will experience lower forces than expected. Fortunately a similar factor also applies to wind loads which determine the practical release pressure value. The low blockage for a louvre, however, enables smooth venting through the louvre during opening with little generated turbulence. This has the effect of limiting the severity of an external explosion and no external explosion has been experienced during tests on this type of relief panel.

A solid panel may experience lift effects at late stages in opening as the gas flows over the top of the panel. This tends to limit the driving pressure at these times. Experiments indicate that the driving pressures on solid relief panels are much less than expected at these late times. Another cause may be the high angular velocities causing suction on the face exposed to the explosion. Louvres do not suffer from this problem to such an extent.

More research is needed to resolve these issues.

A number of simulations based on these equations were performed to determine the opening time 't_o' of a solid hinged panel with a mass density of 20 kg/m². For the purposes of this paper, the α factor was set at 1 for these simulations and it was assumed that an external explosion did not occur during the opening.

The simulations suggest that for a lightweight solid panel the drag and gravity components of the loading may be neglected. The inertia of the outside air near the panel was represented in the simulations by the added mass of a cylinder of air with radius equal to half the panel radial dimension.

Under these assumptions, the time history of the angle 'θ' may be described by the following equation:

$$\theta = \frac{k\,\alpha}{4\,l\,m_e} \left(t^3 - 3\,t_r^2\,t + 2\,t_r^3 \right) \quad (t>t_r) \qquad (4)$$

The parameter m_e, the effective mass per unit area, includes the added mass of the still air outside. The angle is increased and hence the opening time is reduced by minimising the effective mass and the radial panel dimension l. The effect of the rate of pressure rise k is clear from this equation. An earlier release time t_r gives a longer opening time as a result of the reduced driving pressure at early times.

The opening time t_o is defined as the time between the release time t_r and the time at which the vent is effectively open which is set at θ equals 80° following Reference 2.

An example simulation is given in Figure 6 for a panel with a mass of 20 kg/m² with a rate of pressure rise of 5 bar/s. The response is highly non-linear with the time to open by 2% being about 10% of the total opening time. By 30°, the panel has achieved half of the kinetic energy needed for opening and would open in about the same time even if the load was removed. This confirms our assumption of taking the unmodified pressure time histories for the driving pressure as release and possible pressure modification will occur later in the time history.

In the above, it is assumed that an external explosion does not occur during vent opening.

Figure 7 shows the results of a number of vent opening simulations performed for a 20 kg/m^2 solid relief panel. The opening times were calculated for a variety of moderate explosion scenarios of given severity defined by a pressure shortly after opening. The effect of the pressure rise rate 'k' was represented by varying the time for the pressure to reach this value. This time will not correspond to the conventional 'rise time' as we are concerned with the initial stages of the pulse only. Lines of constant 'k' are superimposed on the chart defining the typical range between 2 and 5 bar/s.

A single test result may be identified with a point on this chart. Points on the same contour may then be associated with other loading situations where the opening time will be the same. Acceptable opening times of less than 50ms are indicated by the region of the chart above the 50ms contour. This region of the chart is in a realistic range of loading and so acceptance of the design is indicated for this opening time criterion providing k is expected to be bigger than 4 bar/s.

The fact that the contours in general do not cross lines of constant k indicates that in this case the imposition of an opening time criterion is sensible across a wide range of rise times and pressures. An explosion test with a realistic k will also reflect good opening performance in a wide range of loading situations.

Figure 8 shows the pressure reached in the open position (80°) plotted using the same axes. In this case, the pressure at the open position is taken to be the criterion for acceptance. Again the contours do not cross the lines of constant k and correspond in shape to the contours of opening time. Hence for a solid panel the two acceptance criteria are compatible.

4. CONCLUSIONS

Explosion relief tests have been found to be a very effective method of determining the realistic flow characteristics through louvre panels with a number of advantages over conventional wind tunnel tests.

For lightweight hinged panels the opening time criterion has been found to have general applicability. A realistic test is found to be one where the early rate of pressure rise is typical of the compartment where the panel is to be installed.

Another possible acceptance criterion is the pressure at the open position. For lightweight hinged panels this criterion is compatible with the opening time criterion.

For a hinged relief louvre the driving pressure behaves in a much more complex way which is still under investigation. Further research is needed before the adequacy of the opening time criterion can be confirmed for this method of overpressure relief.

REFERENCES

1. British Gas: 'Review of the Applicability of Predictive Methods to Gas Explosions in Offshore Modules', OTH 89 312, HMSO, 1990.

2. Steel Construction Institute: 'Fire and Blast Information Group, Technical Note on Explosion Mitigation Systems', March 1994.

Table 1 Blast relief panels - Design requirements

1. Geometry

The overall thickness of the wall system shall not exceed 150mm. Panels shall not project more than 800mm in the open position.

2. Weatherproofing

The separation efficiency of the system shall be 100% for droplets bigger than 30 microns for wind velocities between 5 and 10 m/s and rainfall of less than 100 $l/m^2/hr$.

The wall shall withstand external wind and ice forces (velocities dependent on location) and shall be 'rattle free' under severe wind loads.

3. Explosion response

The panels shall open at 50 mbar within a time of 50 milliseconds and remain attached to the frame.

The frame and fixed wall elements shall withstand an overpressure of 0.5 bar and remain in place.

When the panels are open there will be a minimum clear open area of 60%.

FIGURES

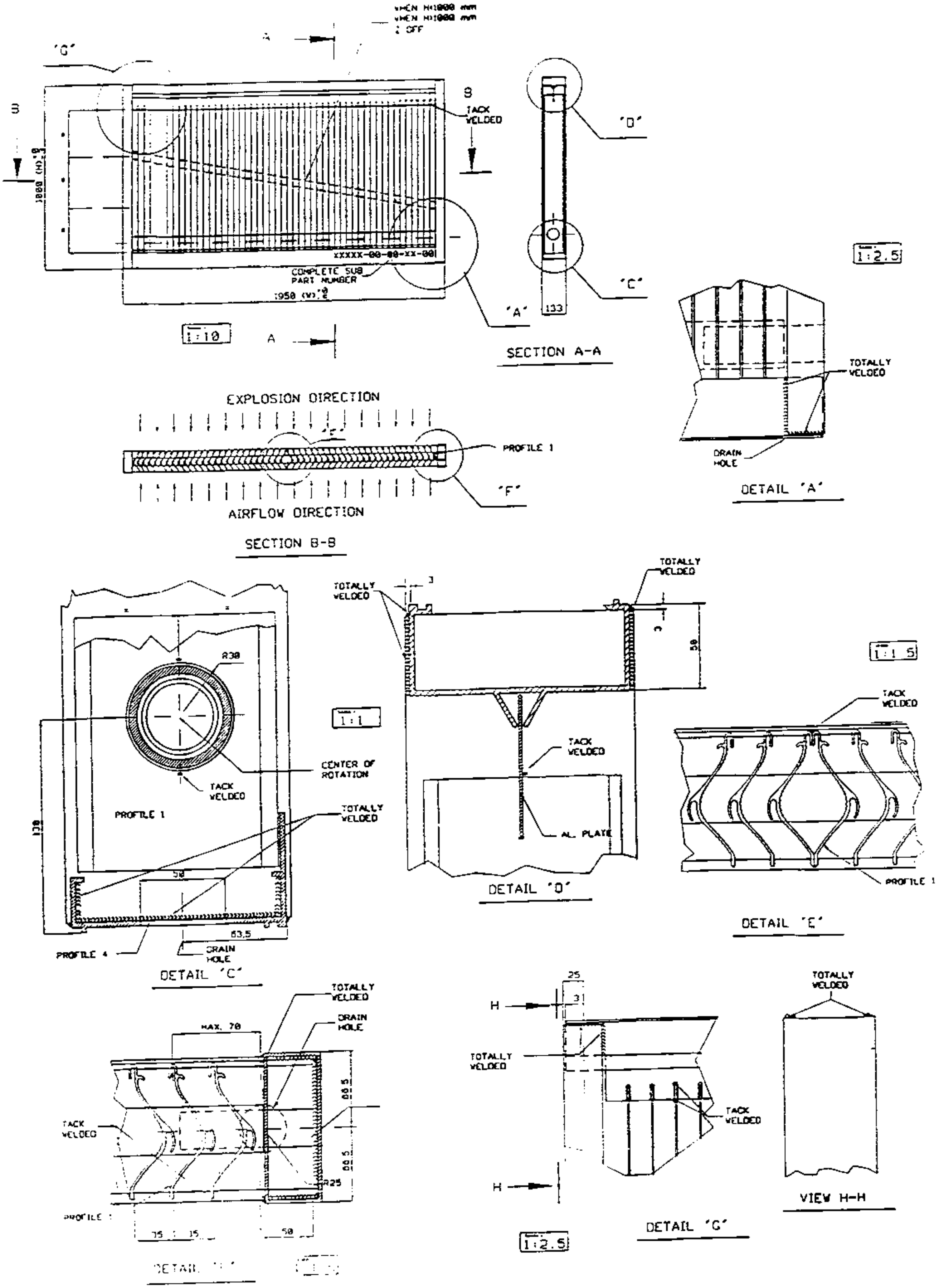


FIGURE 1

EXPLOSION RELIEVING LOUVRE CASSETTE - TYPICAL

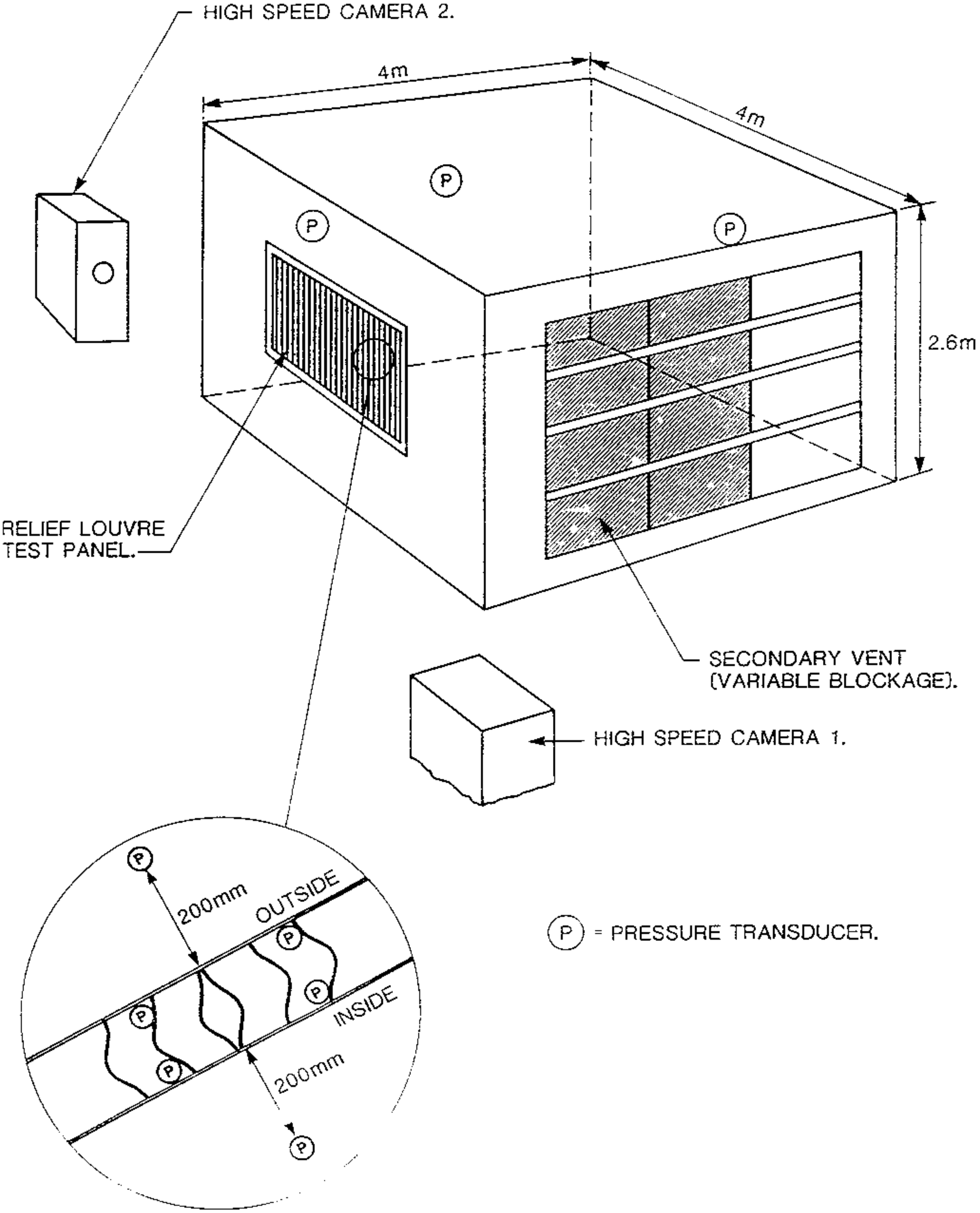


FIGURE 2

TNO TEST FACILITY AND INSTRUMENTATION

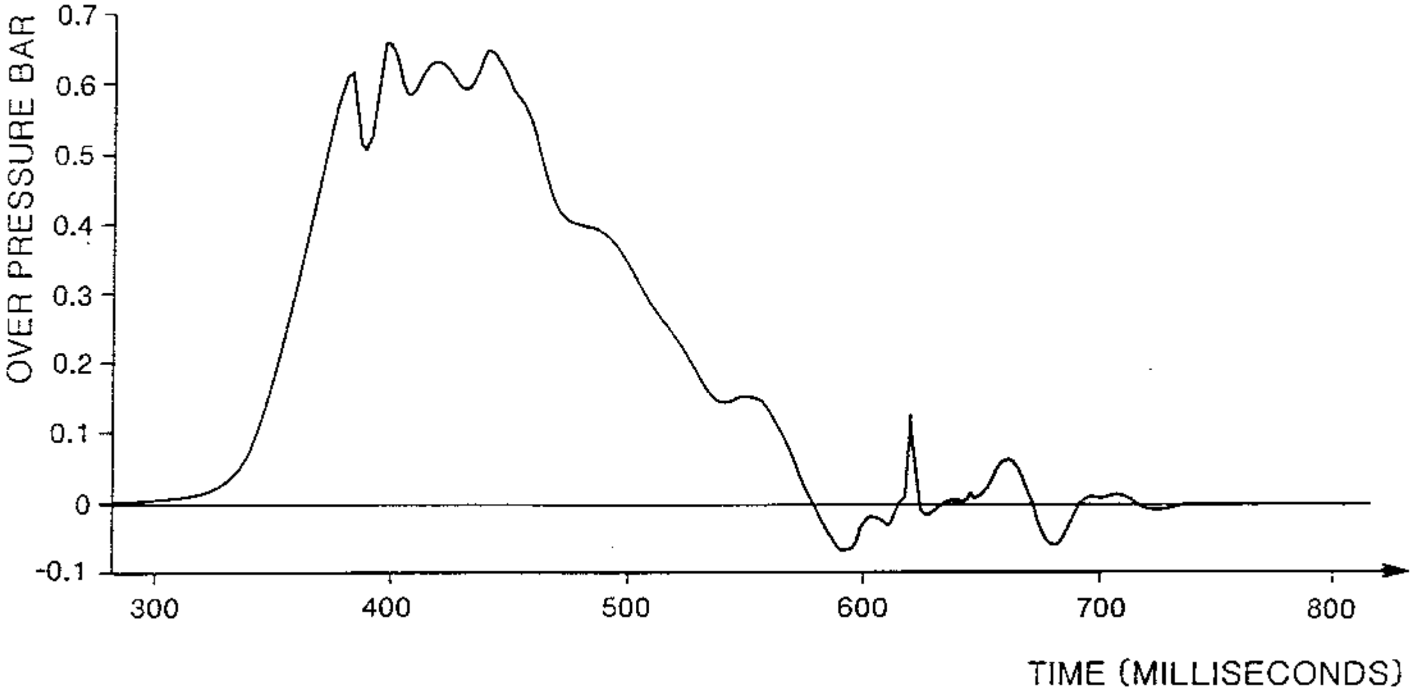


FIGURE 3

TYPICAL PRESSURE TIME HISTORY

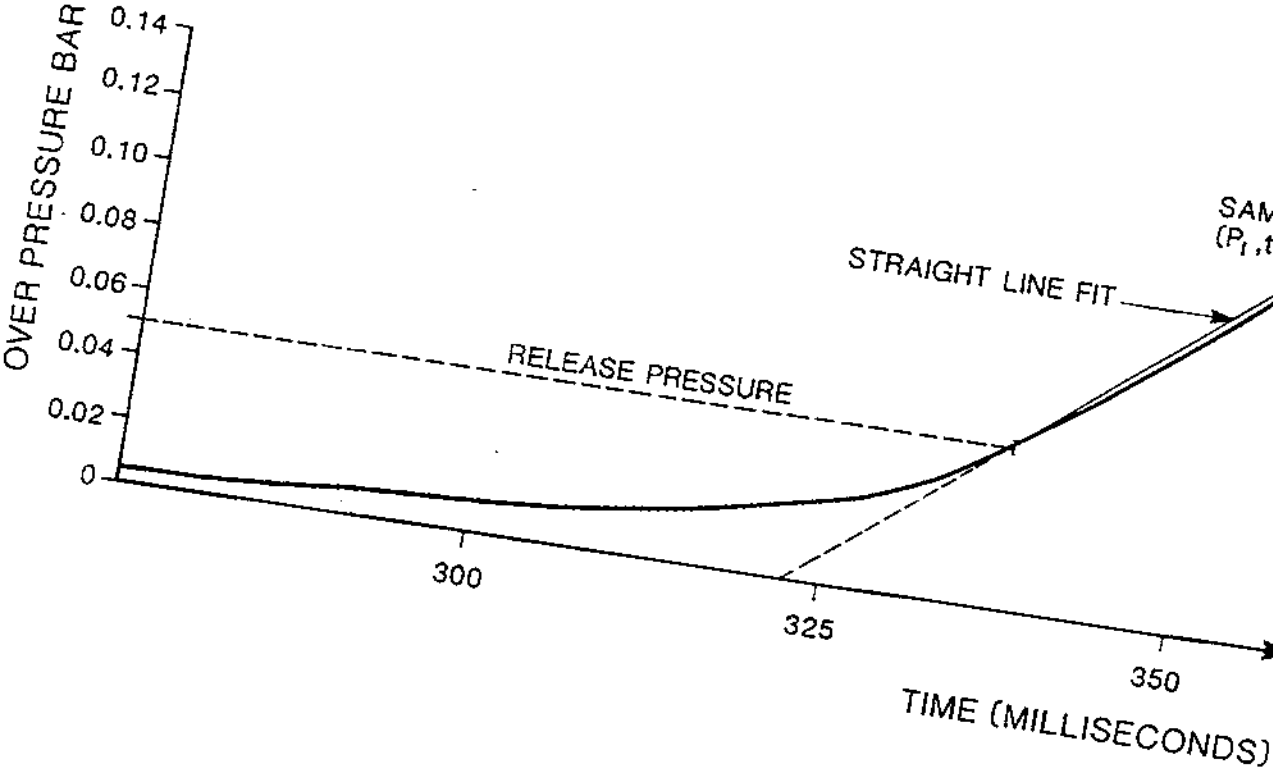


FIGURE 4

TIME HISTORY INTERPOLATION

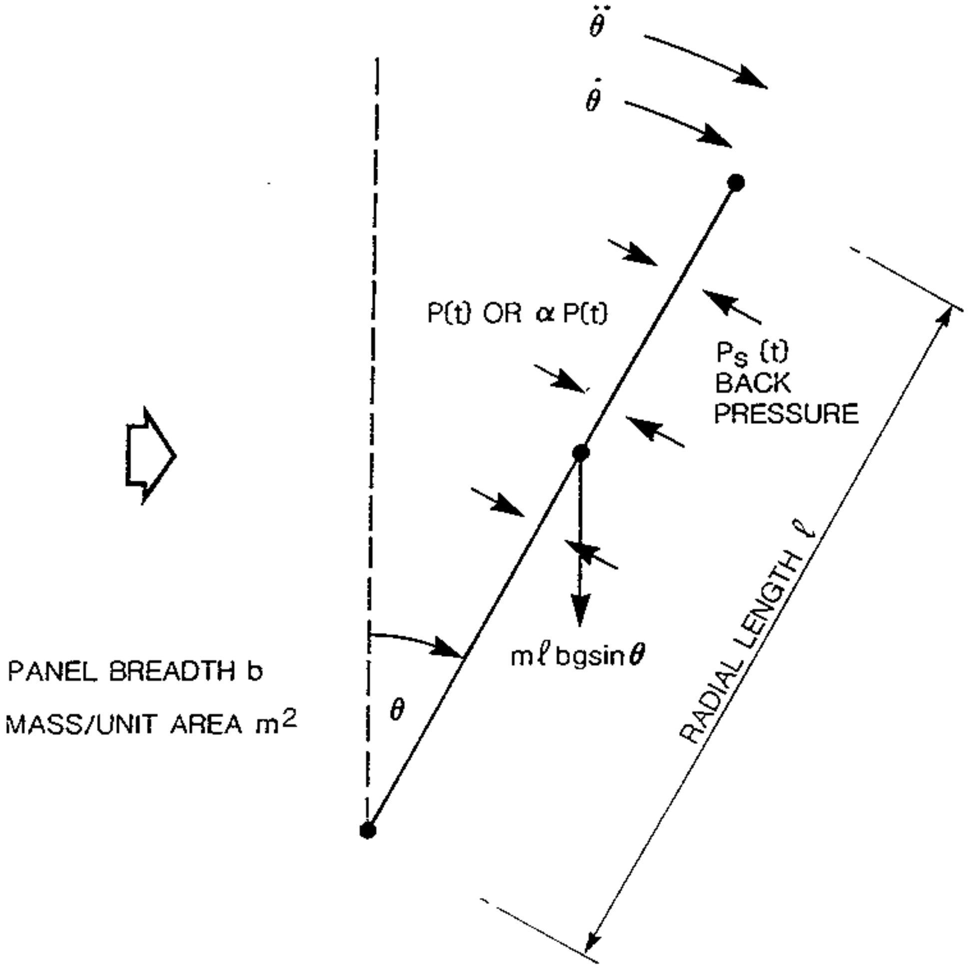
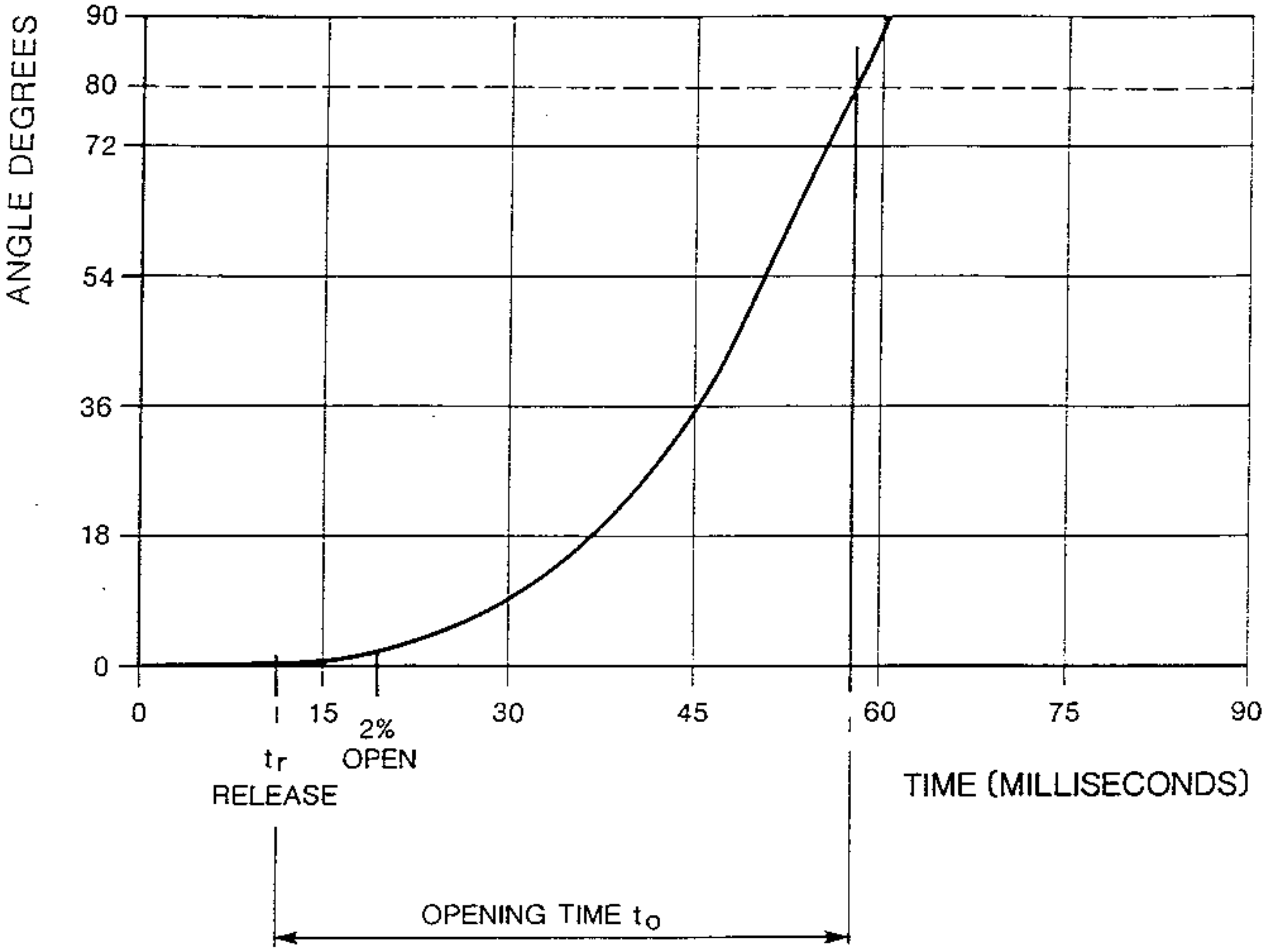


FIGURE 5

VENT DYNAMICS NOTATION



MASS = 20Kg/m^2

FIGURE 6

RELIEF PANEL OPENING TIME HISTORY

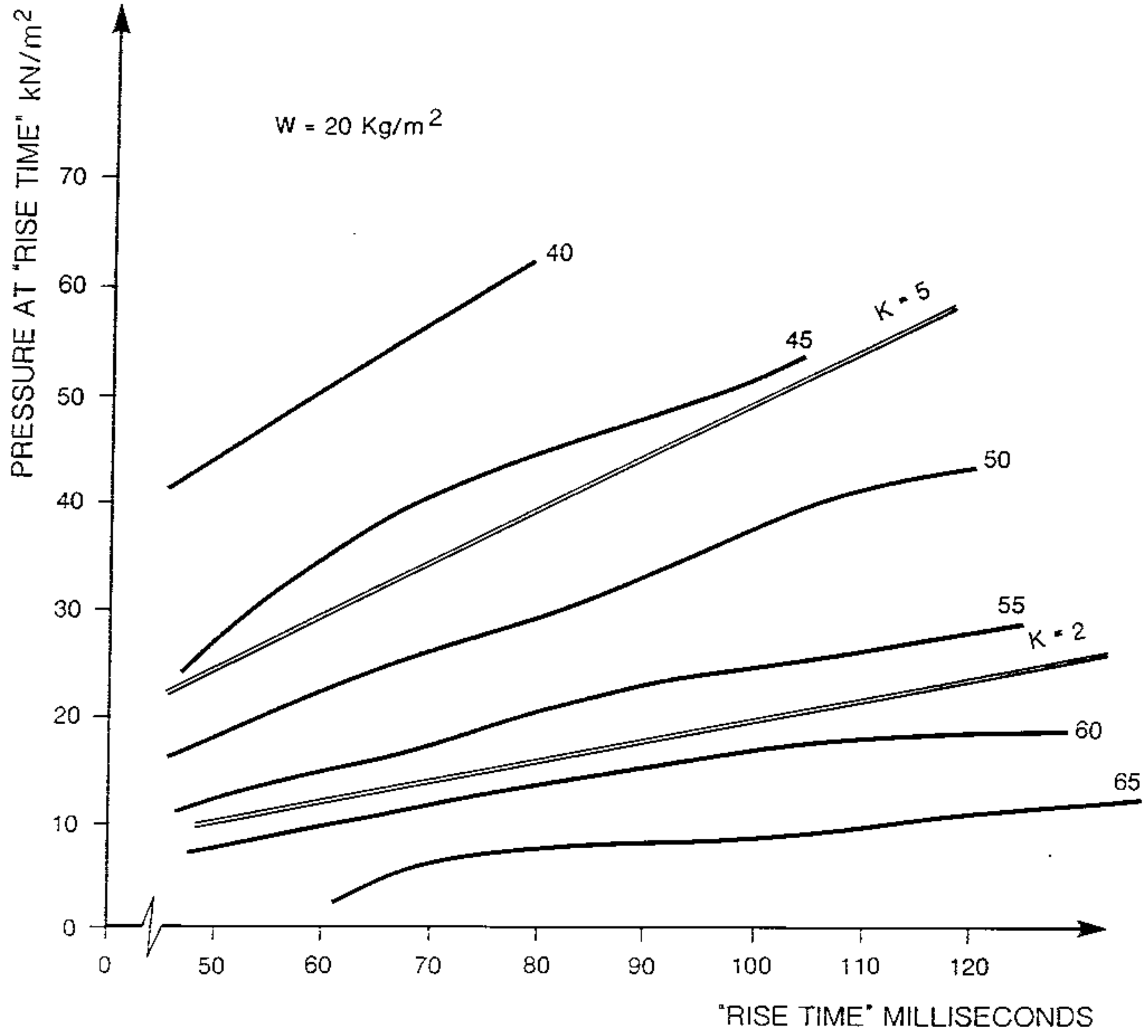


FIGURE 7

DESIGN ACCEPTANCE CHART-OPENING TIMES

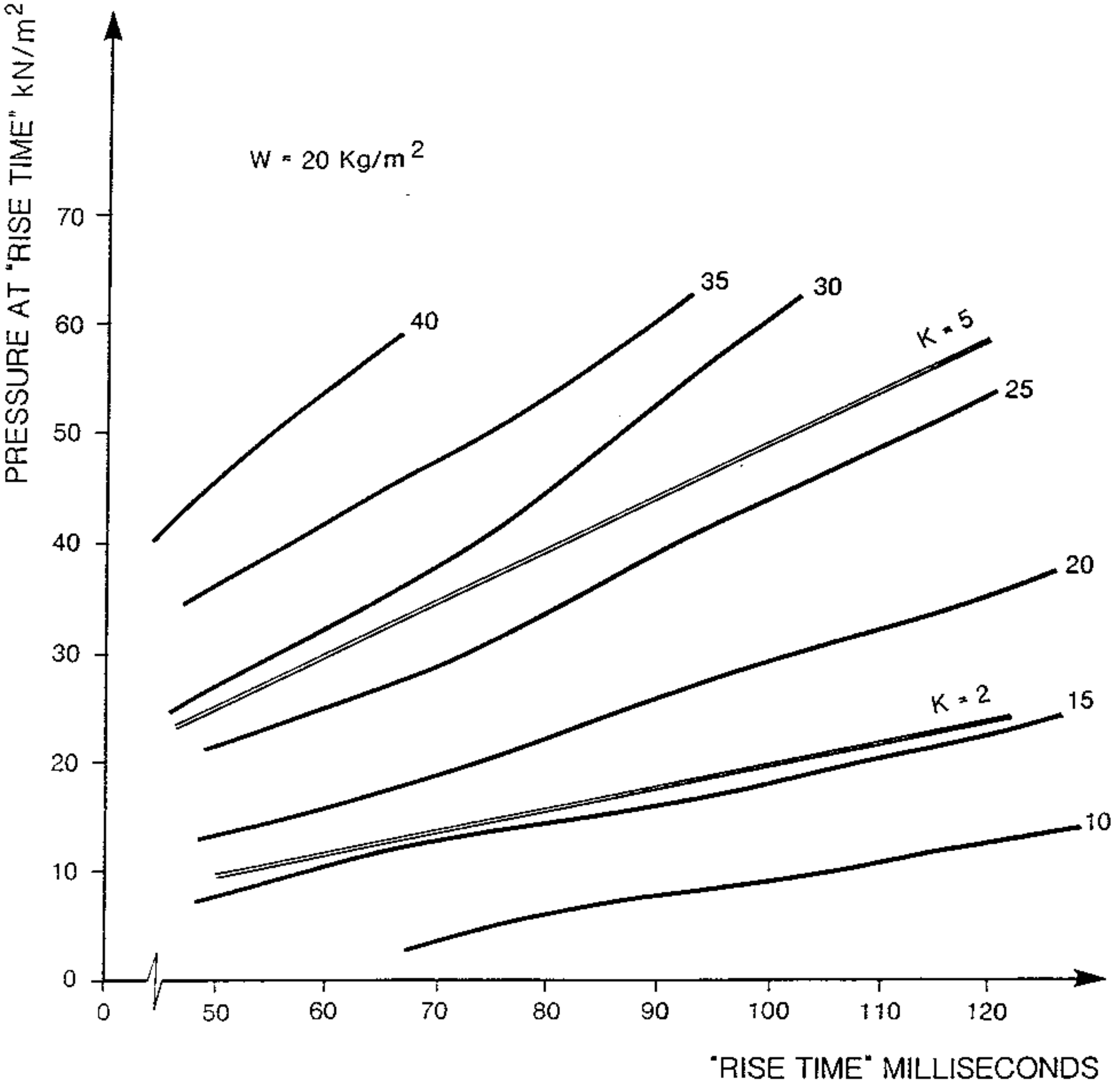


FIGURE 8

DESIGN ACCEPTANCE CHART PRESSURE IN OPEN POSITION