Revised Contents

6 PHASE 2: PRELIMINARY DESIGN

6.1 Introduction

This Chapter describes the development of the design of the lightweight blast walling system and the design of the 1m by 1m test panels for the small scale tests. The blast walling system chosen consists of a number of lightweight panels supported by a steel frame.

The determination of the optimum panel size is discussed based on weight minimisation of the whole wall. Further considerations other than pure bending behaviour have been addressed such as buckling behaviour and the design of connections to the frame.

The blast behaviour of a number of panel options has been studied including corrugated panels, bridge deck type panels, sandwich panels and sandwich panels with rib reinforced cores. The main results of these analysis are described and a panel choice is made. This Chapter also discusses the fire resistance design of the favoured configuration which is the glass reinforced plastic (GRP) sandwich panel.

It has been identified that thin GRP sandwich panels with appropriately designed fixity are one of the most promising concepts. They offer light weight and incorporate thermal insulation in their structural core and skin materials if correctly chosen.

6.2 Design Criteria

6.2.1 Loads

Blast Loading

Explosion simulation work described in the previous Chapter indicates a design overpressure of 1.0 ba,r with a blast duration varying between 100 milliseconds and 500 milliseconds, is appropriate.

Fire

The recommendations published in the Cullen report into the Piper A disaster (16) suggest that the cellulosic furnace test curve should be replaced by the more onerous hydrocarbon curve.

Among the various types of fire expected in topsides of offshore structures are pool fires and jet fires. Pool fires are a major hazard in separation and oil export areas. They can cover whole modules or even engulf the whole platform. Pool fires provide global thermal loading on the module walls. Jet fires are caused by the release and combustion of compressed gases often resulting from the local failure of a vessel or pipe. It is therefore expected in modules associated with gas processing and gas export. The severity of fire loading caused by a jet fire depends on the release rate of gas and its combustion characteristics.

For the preliminary design purposes small scale test panels were designed to H120 rating using the hydrocarbon furnace test curve as a design requirement.

Projectile Loading

Two types of projectiles may be generated in an explosion. Primary projectiles are generated when a vessel explodes and essentially consist of fragments of vessel wall and vessel fittings such as valve stems. Secondary projectiles are loose objects that are entrained by the blast. They are carried from their initial position by drag forces and may be thrown against a blast wall. Secondary projectiles also include objects that are detached from their connections and thrown against the wall. Examples of secondary projectiles are scaffold poles and clips, hard hats, and fragments of steel pipes.

6.2.2 Frame Design Parameters

The most common type of blast wall is the framed structure where the load bearing components are separated into primary (steel posts), secondary (panels), and other tertiary components. The panels are traditionally corrugated steel panels or a combination of steel plates reinforced with channel sections. GRP sandwich panels have been recently employed in framed construction. Blast walls do not normally support any dead loads apart from their own self weight.

In addition to the ability of panels to resist a predetermined blast, the frame which supports them must itself be capable of withstanding the forces transmitted to it.

A number of suggestions of possible frame geometry were put forward and a systematic means of evaluation was required. A parametric study was proposed to determine the form of structural geometry that would resist the design blast with minimum weight. The study was based upon a typical module wall size of 9m long by 6m high, and took account of both beam and column spacing, and the overall support conditions.

Given that the panels had been intended to behave plastically, then it was decided that the design of the support frame should follow a similar approach. BS 5950 addresses the use of the plastic moment capacity of members, and Part 1 of that code is ideal for the design of simple structures such as a support frame. Universal beams were used, reflecting their widespread use in topside construction. BS 5950 increases the design loading by an overall load factor which accounts for uncertainties and variations in both loading and structural behaviour. This load factor was set at 1.00, and so any member with a utilisation of 100% would be on the point of forming a plastic hinge.

6.2.3 Panel Design Parameters

The basic requirements for a fire and blast panel may be summarised as follows:

- it should be capable of withstanding "the worst credible" blast overpressure which is derived from blast and fire assessment;

- it should maintain sufficient strength under fire for a required period of time, be capable of withstanding the erosive and abrasive effects of hot turbulence and picked up projectiles, and be capable of preventing the passage of smoke or flame;

- it should be so insulated that, if either face is exposed to the standard fire test for a predetermined period (e.g. 120 min for A120 or H120), the average temperature rise of the unexposed face shall not exceed a set amount (139°C for A and H fire ratings) above the ambient temperature at any time during that period and the "hot spot" temperature rise shall not exceed a higher set amount (180°C for A and H fire ratings);

In addition, the smoke and toxic emissions must be kept at acceptably low levels and due regard should also be given to the oxygen levels, visibility and air temperature where the human survivability is concerned. Typical areas are the accommodation modules and escape routes. Recognised acceptable limits are as follows: air temperature: not more than 70°C; oxygen: not less than 18%; carbon dioxide: not more than 3%; and carbon monoxide: not more than 0.02%.

6.3 Frame Design

6.3.1 General

A complete blast walling system not only consists of individual panels, but also of means of joining them together to form a complete barrier. A steel supporting frame is common. This type of construction was considered as it allows modular construction and is easy to design and to install. The connection design is also a critical area which will not only affect the structural integrity but also the prevention of the passage of smoke and flames. A number of innovative features were considered such as the generation of membrane effects, adjustable fixing rigidity and damping.

Work was performed to examine the possibility of using extruded GRP sections to construct the supporting frame so that composite action could be achieved and the design could result in further weight reduction. This option was rejected on the basis of cost.

6.3.2 Choice of Panel Size

Since the panel design had not been finalised at the time of this study, the panels used in the model were assumed to have an elastic modulus of just 1% of the nominal value of that for aluminium. This underestimation of the panels' contribution to the wall's overall stiffness leads to conservative member sizes.

Four column spacing combinations, six beam spacing combinations, and four support conditions were selected, giving a total of ninety-six analyses. Each frame was subjected to a combination of a one bar overpressure and its self-weight. Table 6.1 details the combinations.

Average Member Spacings		
Column Spacings	Beam Spacings	Support Conditions
1.0m	1.0m	Edges restrained in blast direction only
1.5m	1.3m*	Pinned edges
1.8m*	1.5m	Built-in edges
3.0m	1.5m*	Cantilevered about base
	2.0m	
	3.0m	
* indicates a centre symmetric, but irregular member spacing		

TABLE 6.1

The analyses package used incorporated not only code checks to BS 5950, but also a minimum weight design algorithm. This was used to iterate from an initial set of member sizes to a final optimum for that configuration. Repeated use of the algorithm had little effect, and the high utilisation factors achieved during the first iteration confirm its efficiency.

6.3.2 Continued

Figure 6.1 shows clearly that the frame weight decreases as the member spacing increases. However, it can be seen from Figure 6.2 that the frame deflections increase once the beam spacing is above 2m. Certainly, the frame weight would be reduced by increasing the member spacing beyond 3m, but the additional deflections, for both the frame and the panels may prove unacceptable. Therefore, a 2m x 2m grid was considered to be the optimum.

6.3.3 Panel/Frame Connections

The novel connection shown in Figure 6.3 was developed. The connection shown acts as a strong and rigid structural joint. At the same time it provides a highly insulated thermal break.

Clear load paths have been provided via the profiled stainless steel covering plate which is tightly bolted by using high strength friction grip stainless steel bolts. The covering stainless steel plate not only ensures the structural continuity from one panel to another, it also distributes load evenly to avoid stress concentrations which could be potentially damaging to the GRP skin. Furthermore, the profiled clip-lock connection of the covering plate allows the easy installation of an additional sandwich covering piece and holds it for as long as required when subjected to a fire.

The box section within the panel, stiffens the edge and directly takes the bolt loads. The staggered connection eliminates a direct heat path and provides a total barrier to flame, fumes and smoke.

The connections are also designed for ease of installation.

6.4 Panel Design Against Blast

6.4.1 Blast Panel Parametric Studies

Computer software was written to calculate the moment capacity of a general section when one of its extreme fibres reaches a specified yield stress (the effective yield condition). This moment capacity was then converted into a pressure rating given the span and fixity conditions. The section parameters consistent with 1.0 bar pressure rating and the mass were noted. Table 7.1 of Reference 3 lists the optimised section parameters that have achieved a 1.0 bar pressure rating.

It was appreciated at this stage that the section parameters could be changed significantly when considerations other than one dimensional bending were taken into account. Five factors were identified that would result in further changes in the section parameters:

(1) Where panels may be considered isotropic in the plane of the panel, two dimensional plate action may prove beneficial.

(2) In orthogonal panels where bending stiffness in one direction is much greater than the other, plate action may prove disadvantageous.

(3) Thin sections would not necessarily satisfy the shear requirements.

(4) Given the low elastic moduli of aluminium and GRP the thickness of elements may have to be increased beyond that necessary to satisfy bending requirements alone.

(5) Section thickness might need to be increased to improve impact resistance and fire performance.

To achieve a better understanding of the two dimensional bending problem five different configurations were selected for finite element modelling to represent three generic types of panel:

6.4.1 Continued

(1) A single skin, profiled, panel. In this category the corrugated and sinusoidal panels were chosen.

(2) A stiffened panel. In this category the corrugated panel with a cover plate was chosen because it was found to be promising in terms of weight. This panel is subsequently referred to as the “Bridge Deck” panel.

(3) A sandwich panel with an isotropic or orthotropic core. In the isotropic case, a PVC foam core was chosen and in the second a triangulated core was assumed.

In the first instance all panels were analysed statically. Given its simple configuration and low cost of analysis, the sandwich panel with the foam core was chosen for further analyses such as elasto/plastic, natural frequency, and time-stepping dynamic analyses. Where possible, correlation with analytical solutions was examined.

6.4.2 Blast Resistant Design

The effects of materials and panel configurations have been systematically investigated with respect to the implications on weight per unit area, deflection and natural periods and the results were summarised in Table 7.1 of the second progress report (Reference 3) for aluminium and GRP panels.

An important development with respect to blast resistant design is the mobilisation of membrane effects. Membrane loading in a panel utilises the full thickness of the panel as the in-plane stress is constant throughout the thickness and the whole section may be stressed to its full capacity simultaneously.

Due to the low modulus (or stiffness) of GRP materials, they tend to have large deflections and therefore are very suitable for membrane structural design. By restraining the in-plane deflection a significant in-plane tension is generated which will resist the blast overpressure and reduce the bending moment at the middle of the panel. By mobilising the membrane effects, it is possible to design panels that are considerably thinner than their pure bending counterparts, and furthermore we have turned the weak point of low modulus of GRP to be a favourable point in design.

It was found that, due to the elasticity of support structures, there is usually some reduction in the membrane force as compared with that in an idealised case. This reduction could be significant if the fixing details are inappropriate. A reduction factor was derived, following the analysis, which was included in the panel design.

A study was performed to examine the damping effect on the reduction of the peak blast response. This effect is usually neglected in such analyses. Based on a single degree of freedom analysis, it was found that the peak blast response could be reduced by as much as 14%, assuming the existence of a large but realistic damping of 10% of critical.

Preliminary investigations were also made into a novel concept of a spring damper absorption blast panel as described in Appendix F of Reference 2 . This concept incorporated a rubber/synthetic connection between the front and the back face of the panel which introduced damping into the system and also provided a thermal break. This panel was not pursued further on the basis of cost.

6.4.3 Selection of Configuration

Three generic types of panels were investigated and reported in Progress Report 1 (2). These were:

(1) Profiled single skin panel. (Corrugated)
(2) Stiffened panels. (Corrugated plus a single covering sheet)
(3) Sandwich panels. (PVC foam core and reinforced core with triangular ribs)

The primary structural materials that were considered were:

? Aluminium alloys (6082)
? Glass reinforced plastic GRP
? Steel (galvanised and stainless steel)

The structural performance of these panels was discussed, based on one dimensional analytical calculations and finite element analysis. The main conclusions were that aluminium alloys and GRP offer similar structural weight savings and both are effective. However, in terms of fire protection, aluminium alloys may require more insulation materials than GRP because, to a certain degree, GRP is an insulation material in its own right. GRP, therefore, has been selected as the primary structural material for the integrated fire and blast panels.

Figures 6.4 and 6.5 show sample results from the finite element analyses. Stress contours are shown for a sandwich and corrugated aluminium panel.

A sandwich type of configuration was selected for production of small scale test panels. Some alternative configurations, such as corrugated sheeting, offer greater weight saving advantages, but there is great uncertainty about how to attach insulating materials to meet the fire protection requirements.

The basic panel design is shown in Figure 6.6. It consists of two GRP laminate skins with a rigid insulating core sandwiched between the two skins. The panel was designed to resist fire and blast from either side. As a result it is of symmetrical construction. The connection details are shown in Figure 6.3.

The sandwich construction technique also offers an excellent combination of light weight, high stiffness and good thermal insulation characteristics.

In comparison, monocoque (or single skin) panels do not use material efficiently and often result in excessive weight and high material cost. The structural efficiency of a monocoque panel may be improved by stiffening it with conventional ‘top-hat’ stiffeners. However, this may lead to other problems such as fitting difficulties or failures due to stress concentration and debonding between the stiffeners and the panel. Stiffened panels are prone to these failures, especially when they are subjected to thermal stressing or lateral blast loading. More details are given in Reference 2, where it is also recognised that sandwich panels would provide an effective solution which would eliminate the drawbacks associated with the discrete stiffeners.

6.5 Panel Design Against Fire

6.5.1 General

The blast response calculations indicated that thin GRP sandwich panels, with appropriately designed fixity were amongst the most promising concepts. Work, therefore, concentrated on their further development.

With respect to the fire performance, modifications were introduced to the basic panel design to produce variants to meet special performance requirements. One of the modifications was to apply an external intumescent coating to give extra protection against flame erosion and weathering. This variant might be necessary for protection against high pressure jet fires.

The basic panel was however used for the small scale tests. A steel channel section was designed for inclusion around the edges of two of the test panels to generate the required in-plane restraint as described in Section 6.6.1.

When the panel is exposed to fire, the resin in the outer skin will either burn off (or char in the case of a phelonic resin) within a couple of minutes. The woven rovings (WR) glass mats which form the reinforcement in the GRP, act as a fire and abrasion barrier to slow down the flame penetration and greatly reduce the rate of damage to the inner layers. The conduction of heat is primarily resisted by the high performance insulating core. As a result a large temperature difference is attained; the back face is kept cool while the hot face rises rapidly to over a 1000°C.

The stability of the insulating core relies on the support of the back face as the bonding between the core and the front skin will have disintegrated with the rapid rise of the front face temperature.

A large amount of information was collated and assessed on the available insulating materials which could be potentially used for the core, and similar information was gathered on high strength structural materials suitable for the skins.

A number of analyses were performed to simulate the panel’s thermal resistance based on both analytical and finite difference methods.

The analytical method assumed a linear temperature distribution through the wall thickness and a constant hot face temperature. This method was used for comparing one material with another and not for sizing as the results are conservative. Derivations are given in Appendix B of Reference 4.

Computer programs based on a finite difference time-marching technique were developed. The theoretical background and sample computer output are given in Appendix C of reference 4. The software was developed for multi-layer composite panels. The variation of thermal conductivity and thermal diffusivity with temperature was represented.

Another possible failure under fire is the debonding of the core from the back face as the temperature rises. As the in-place stability of the core usually relies on this bond, the core would simply drop off if such a failure occurs. Therefore, it is important to use an appropriate adhesive which is capable of functioning at elevated temperature.

6.5.2 Selection of Core Material

When selecting core materials, the primary concerns are similar to those for skin materials, but the following properties have become the top priority:

thermal conductivity
thermal diffusivity

For a given wall thickness and design fire event, the rise of the back face temperature is essentially determined by the insulation properties of the core, particularly the thermal diffusivity at the initial stages and the thermal conductivity as the temperature stabilises. The thermal diffusivity is defined as the ratio of the conductivity to the product of the density multiplied by the specific heat. The lower the conductivity, the lower the back face temperature.

A simple analysis was carried out regarding the effect of thermal diffusivity on the characteristics of heat transfer and its implications on the selection of insulating materials. Details are given in Appendix A of reference 4*. The main outcome of the study was that it is desirable to choose materials with the minimum thermal diffusivity for a given thermal conductivity.

When calculating the minimum thickness of the insulating core, it needs to be borne in mind what the differing working temperatures of each ingredient material in the core and the skin are:

resin: 200°C
normal glass: 650°C
high temp glass: 1100°C

As temperature on the hot face exceeds the normal working temperature, materials may start to go through significant chemical and physical changes.

Extensive calculations have been carried out for all insulating materials that have been regarded as potentially suitable for the construction of the core and where property data is currently available. The results were presented in progress report 4.

Figures 11 to 16 of reference 4 summarise the results for a number of materials. For each material the relationships between the wall thickness and back face temperature are plotted at a time of 1/2 hour, 1 hour and 2 hours.

It was found that when a thin GRP back face sheet is included in the calculation, there is only a small amount of reduction in the core thickness.

A good core material for a fire and blast panel is the one that gives a combination of good thermal and mechanical properties. It should have low thermal conductivity and high specific heat combined with adequate compressive and shear strength.

A range of polymer foam core materials are available for sandwich construction. These materials usually have good thermal insulating properties, but some are susceptible to fire damage and should be avoided. It has been found that several lightweight foams can be ignited with a match.

Phenolic based foams such as Plasticell LST II and Koolphen give the best fire performance. They are difficult to ignite and are self-extinguishing. When exposed to fire the outer surface forms an intractable char which protects the inner material.

In the design, SLP first calculated the mininum required insulating thickness and then checked the design against blast resistance and shear strength of the core. It was found that the fire performance usually dictates the minimum required core thickness.

6.5.2 Continued

The calculated minimum insulating thicknesses of various materials are given in Table 4.4 of Reference 4. The results in the table only serve as an indicative comparison of the relative thermal insulating performance of different materials.

The calculated minimum thicknesses were found to be larger than those indicated in published fire tests (see Reference 4). The minimum required core thickness, and indeed the panel thickness as a whole, should be determined from test results as well as theoretical calculations.

6.5.3 Selection of Facing Laminates

When selecting the skin materials, in addition to the general considerations of strength, the following properties were of primary concern:

? combustibility
? toxicity
? smoke and fume emission
? melting or char temperature
? softening temperature
? density

The other thermal properties that are also of concern are:

? thermal expansion coefficient
? thermal conductivity
? specific heat
? thermal emissivity

The thermal expansion coefficient governs the compatibility of materials for skins, the core, fixtures and fittings and is considered in conjunction with all connected components.

Phenolic resin was chosen primarily for its superior fire performance with respect to smoke production and toxicity. In these aspects, phenolic resin is far better than other thermosetting resins such as unsaturated polyester, although it has similar mechanical and corrosion resistance properties.

Resins

Phenolic resins were chosen as the preferred resins because they offered the best fire performance and had the lowest smoke production and toxic emissions. They have better strength retention (as a proportion of the strength at 20°C) at elevated temperatures to the other resins. Upon exposure to fire, phenolic resins undergo progressive condensation to form an intractable char which protects the remaining composite.

Epoxy resins are another option. They have better mechanical properties than phenolic resins at normal temperatures, but they have higher levels of smoke and toxic emission, they are more expensive and more difficult to manufacture as they require stepped temperature curing.

Polyester and vinylester resins are not specified for the testing panels as they have inferior fire performance to phenolic resins. In addition to their known high levels of smoke and toxic emission a further drawback of polyester is the low flashover point. Flashover refers to the rapid transition from a localised fire to the general conflagration within the compartment when all fuel surfaces are burning simultaneously

6.5.3 Continued

For the fire and blast panels which are designed to be lightweight yet strong, the best form of reinforcement is a woven roving (WR) fabrics/mat. The use of WR reinforcement allows a high glass fibre to resin ratio to be achieved, which consequently gives high stiffness and strength

Interlaminar shear failure is a critical failure mode for laminates subjected to lateral blast loading. It is believed that the interlaminar shear strength can be improved by incorporating some chopped strand mat (CSM) glass reinforcement between layers of woven roving reinforcement.

From past experience, it is known that a thin layer of GRP laminate is vulnerable to the erosive and abrasive effect of fire. A GRP skin can be lost quickly in a fire leaving the core exposed to the flame. Under such circumstances, the core material can be stripped away by the hot turbulent wind or start to burn if an organic foam core is used. Both lead to the failure of the panel.

To resist a 1 bar blast overpressure, it has been shown that the minimum required laminate thickness is only about 5 mm. A laminate of this thickness has limited ability to maintain its integrity and to prevent the flame penetrating into the core material.

To enhance the structural integrity of the laminates under fire, two materials were identified which would increase the fire resistance without generating additional toxic products. Those are:

- Ceepree additives;
- TYGLAS 1000C high temperature fabrics.

A third option was to use stainless steel wire mesh in the facing laminate. The uncertainty associated with this option was the effectiveness of the bonding characteristics of the metallic mesh in a high glass content laminate and the effect of the acid on the metal during curing.

The Ceepree and the TYGLAS 1000C additives were included in the small scale testing programme skins.

6.5.4 Indicative Fire Tests on Laminates

Following the arrangement between SLP Engineering and Brunner Mond Ltd, the supplier of Ceepree, TNO delivered a total of eight GRP plates measuring 1 foot square to Brunner Mond for indicative fire testing.

The plates had the following composition:

(1) Epoxy 0% Ceepree
(2) Epoxy 5% Ceepree
(3) Epoxy 15% Ceepree
(4) Phenolic 0% Ceepree
(5) Phenolic & TYGLAS 1000
(6) Phenolic with pultrusions
(7) Polyester 15% Ceepree
(8) Vinylester 15% Ceepree

The plates were mounted to the testing section of a small electrical radiation oven. A simulated hydrocarbon temperature time history was generated to test the fire performance of the plates.

The purpose of the tests was to assess the relative performance of different resin systems with particular emphasis on the effectiveness of Ceepree materials in resisting fire.

6.5.4 Continued

SLP witnessed some of these indicative fire tests and furthermore contacted BP to discuss the test results. A testing report was received from Brunner Mond which detailed the observations made during the test.

Tests were stopped either after the cold face caught fire, typically around 20 minutes, or after 60 minutes when the temperature had reached a steady state.

6.5.5 Selection of Configuration

In view of the wide availability of resins and core materials, it was decided to test six 1 m x 1m panels with different material combinations and configurations. Phenolic resins were chosen as the primary resin systems. Panel details of initial design are given in the CAD Drawings Nos. HA215-001 to -007, Revision A (Rev. B for HA215-005) given in Reference 4.

The full scale panel thickness is used for the 1 m x 1 m test panels in order to test the fire performance. The composition of the six panels is summarised in the next Chapter

Preliminary drawings were sent to a number of GRP manufacturers for discussion. Manufacturers were warned of the known poor curing problem which has been previously experienced in "acid cure" phenolic resins with Ceepree additives. In an attempt to find a cure solution, several manufacturers carried out independent trial tests of "acid cure" phenolic resins with Ceepree. The initial outcome was disappointing as it was universally found that there was no cure at all of "acid cure" phenolic resins with Ceepree.

Recognising the problem of curing phenolic resins with Ceepree, the Ceepree supplier has embarked on intensive research aimed at modifying Ceepree to make it work with "acid cure" phenolic resins and some progress has been made. With 30% of a modified grade of Ceepree, "acid cure" phenolic resins have cured after two hours at 80°C in a standard uncontrolled "pot cure" test.

Despite the encouraging results, it was decided that further research was still required before the curing problem is completely eliminated from GRP laminate production. Therefore, after consultation with TNO and the resin supplier, it has been decided to opt for a different design to avoid the present curing problem of Ceepree with phenolic resins.

The revised design made use of different materials in the front face and the back face in most panels. The outer skin is mainly based on epoxy resins with Ceepree additives to retain good structural integrity at high temperature, while the inner skin is based on phenolic but without Ceepree.

The revised details of panels are given in Drawings Nos. HA215-001 to -007, Rev. 0

6.5.6 Cost and Weight Estimates

A number of GRP manufacturers have been contacted in relation to the fabrication of the test sandwich panels. It appears that the best production method is probably either a pressurised resin injection system or a vacuum assisted resin injection system, both using a closed mould. These two methods offer efficient production, consistent thickness and panel quality. However, for the fabrication of a few sample panels, the tooling cost is very expensive, particularly for the pressurised resin injection. Both methods have been offered by manufacturers for fabricating the test panels. The cost of using a closed mould system was about £5000 to £7000 for fabrication of the six test panels (£600/m^2).

In comparison, the hand lay-up method is simple and very cheap, but the quality control is difficult as it is individual dependent. The hand lay-up method was also offered by a manufacturer and at half the cost of the closed mould methods.

6.5.6 Continued

The weights of the test panels were all similar at 35Kg/m^2 which compares well with a typical steel blast wall at 70 to 100 Kg/m^2. Typical costs for manufacture at steel blast walls have been found to be about £600/m^2 for large total areas. It is expected that the GRP sandwich fire and blast panel could be manufactured at a lower price.

6.6 Design for Small Scale Tests

6.6.1 General

The purpose of the tests is to establish the performance of various panel options, which include different material combinations and structural configurations, and to ascertain whether there are any inherent problems.

Drawings for fabrication of small scale panels were produced. The panels were full scale with respect to thickness to enable subsequent furnace fire testing.

A steel frame was provided round the panel to mobilise in-plane membrane forces in the panel. These tension effects have the effect of lowering the stresses in the material for a given pressure loading and limiting the out of plane deflections. It was hoped that this would provide a lighter panel than the conventional similar panels available which resist pressure in bending only. There was also the additional benefit in that the two skins acted together more effectively.

In order that the actual panel thickness may be used for subsequent furnace tests, the full scale thickness is used for the small scale-test panels. As a result, the test panels with one metre span will be able to withstand overpressures around 2 bar when tested with edges restrained. The maximum value could be as high as 3 bar, depending on the edge fixity

The attachment details described in Section 6.2 were designed to enable fixed or pinned boundary conditions to be simulated. Use of both of these fixities will enable calibration of the equation parameters and enable a direct comparison to be made.

A second panel without the restraining steel edge will also enabled the effect of membrane forces on the response to be quantified.

6.6.2 Attachment Frame

This section deals with the design of the attachment details for the small scale test pieces.

The maximum thickness of the panels was 100mm. With some allowance for packers and special attachments, this would give a required overall thickness of 140mm.

It was also desirable to test the panels with differing boundary conditions such as with simply supported edges. This was achieved by inserting a steel strip with a semi-circular outstand above the panel such that the panel is in contact with the outstand and is able to hinge through a small angle without restraint. As maximum displacement is often the dominant limiting criterion, this capability was important.

6.6.3 Inclusion of MICROTHERM Panels

A number of meetings were held between SLP and the manufacturer of the Microtherm core material. The material has excellent fire resistance as discussed in the Progress Report 3 (Reference 4), but it is expensive and in loose form. However, during the meeting the manufacturer stated that a cheaper option was available by supplying the material in the form of pre-fabricated honeycomb panels with the Microtherm infill. They further agreed to supply, free-issue, sample core panels for the project.

To assess the blast resistance of the core material, SLP obtained a test report from the manufacturer on this form of core, and performed an independent evaluation. The test panel measures about 3 m square and it consists of three 1 m x 3 m sandwich panels made of 35 mm thick Microtherm honeycomb core and 0.5 mm thick stainless steel skins on both sides. The three panels are butt joined together with two pairs of joining pieces. The depth of this shaped section is 36 mm and the width is 145 mm.

The analysis showed that the combination of a honeycomb matrix with the Microtherm infill material had adequate strength for the use as a core material for a fire and blast panel. It was therefore recommended to be used as an alternative to the original grid pattern matrix design in the test panel No. 6.

8 PHASE 4: DETAILED DESIGN OF CHOSEN CONCEPT

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CHAPTER 8 PHASE 4: DETAILED DESIGN OF CHOSEN CONCEPT

8.1 Introduction

The primary scope of work covered in this Chapter is the review and assessment of the performance of alternative 1 metre square GRP sandwich panels, subjected to blast and fire tests at the TNO Prins Maurits Laboratory during the small scale tests.

The second major task consisted of finalising the design of the large scale panels, with the preferred panel arrangement and core material. Shear testing of the core material to the ASTM-C27 standard was also performed to establish the shear strength of the core and its adequacy of ensuring that composite action between the components of the panel develops.

From the results of the small scale testing programme, a preferred panel arrangement and associatedsupport conditions were identified. Design drawings of the test specimen and support framing were produced and supplied to TNO for the purpose of material procurement and setting up of blast and fire tests.

The design philosophy adopted was that the wall should take the loading of an explosion followed by a fire. After being subjected to a blast loading the wall should retain its integrity although some deformations may be generated. It should then maintain the tightness for flames, smoke or fumes and sustain a hydrocarbon fire for up to 2 hours.

8.2 Preferred Panel Configuration

After an extensive review of possible materials for the facing skins and cores of sandwich panels suitable for withstanding a 1 bar overpressure and providing H120 fire rating, six candidate panel configurations were identified. The selection process is discussed in detail in Progress Report No. 3 (Reference 4).

The configurations tested were:

(1) Epoxy resin GRP external facing skin with Ceepree additive
Phenolic resin GRP internal facing skin
Koolphen K160 foam core
Bolted end fixity, through steel frame.

(2) As (1) but with Plasticell LST II core.

(3) Phenolic resin GRP external and internal facing skins with Tyglass reinforcement
Koolphen K160 foam core
Bolted end fixity, through steel frame.

(4) As (1) but with pinned end fixity, steel frame in-plane restraint.

(5) As (1) but with simply supported end fixity, no frame.

(6) Phenolic resin GRP external and internal facing skins
Honeycomb core (Zortech)
Bolted end fixity, through steel frame.

Details of the testing and results obtained are included in Chapter 7 but, in general terms, all panels met (or nearly met) the required blast criteria.

8.2. Continued

The test procedure aimed to initially subject each panel to a 1 bar static pressure and then apply three target blast overpressures (1, 1.5 and 2 bars). In summary, the blast performance was as follows:

Panel	Static Test	Dynamic Test*
1	_	Damaged at 1.6 bar
2	Loss of stiffness at 0.8 bar	-
3	_	_
4	_	_
5	_	_
6	Loss of stiffness at 0.4 bar	_

* [Due to scaling effects, the desired 1 bar design overpressure is equivalent to 2.6 bar in the 1m x 1m panels.]

The stiffness drop during both static and dynamic tests was believed to be associated with debonding of core and skins.

Within expected experimental scatter and repeatability of blast testing, the resulting blast resistances of all test panel configurations were considered to be satisfactory although requiring some minor redesign. The panels for the fire tests (Panels 2, 3 and 6) were therefore selected to cover various through-thickness property combinations, fixity conditions not being a consideration in this instance.

Test results for the three panels indicated that their fire performance was less impressive than their blast resistance. Panels 2 and 3 were far from meeting the H120 specification. The panel with a Zortech core (Panel 6) was close to achieving the fire test requirement and, with some identified modifications, it was believed that the specification could be met.

From the blast and fire test results, it was decided that the basic panel configuration for prototype development would be:

- Phenolic resin GRP external and internal facing skins
- No additive to the GRP skins
- Honeycomb core (Zortech)
- Fixity condition : to be decided.

Epoxy resin appeared to add no detectable benefit in performance and, due to its toxicity and higher cost, was dropped in favour of phenolic. In addition, by adopting phenolic skins, both faces of the panel could be identical - this allowed greater flexibility in application since fire/blast attack could be accommodated from either direction.

Ceepree additive and Tyglass reinforcement also seemed to have added little to the panel performance and they did not justify the additional costs in terms of material and labour.

The Zortech honeycomb core was needed to achieve an H120 rating - all other core materials proved to be inadequate.

8.3 Further Work for Phase 4

Further refinement of the design was then required to:

- Establish the Fixity conditions for the prototype panel, bearing in mind the need to minimise weight/cost of the overall walling system (i.e. panels and support frame).
- Achieve a better bond between facing skins and core material. Possible mechanical fixings were investigated to further enhance the interface adhesion and avoid delamination during blast loading.
- Arrange the panel around a single layer of Zortech - the 50mm thick core in the test panel consisted of two layers of approximately 40mm and 10mm. This created an unnecessary additional interface with the possibility of de-bonding.
- Confirm the size of the full scale panels (approximately 2.5m x 2.5m) and design the framing system.

These objectives were achieved as far as was envisaged at the time. An overview of the design process is given in the following Section.

8.4 Panel Design

The results of the small scale blast tests followed by fire tests indicated that additives to the GRP skins did not greatly benefit the capacity of the panels to blast loading and did not justify the high cost involved in using additives, nor indeed did they provide significant improvement to their fire performance. Amongst the various core materials used, the advantages of using Micropore's Honeycomb Reinforced Board (HRB) were evident.

The objective of the design was to produce a system which is capable of withstanding a 1 bar overpressure explosion, and subsequently achieve an H120 fire rating.

The design of the large scale panel and support frame was performed on the basis of the philosophy adopted throughout this development programme, which was used for the design of the small scale specimens, that the panel should resist blast overpressures by developing in-plane membrane action. The supporting frame was designed to withstand such in-plane reactions.

The basic section dimensions were kept the same as those of the small scale panels. The resulting final panel configuration was:

- 2.5m x 2.5m panel;
- Phenolic resin GRP external and internal facing 6mm skins;
- No additives to the GRP skins;
- A single layer of 50mm honeycomb core (Micropore);
- Structural adhesive to provide as near as perfect a bond between core and skins:
- Pulltruded 50x50x10 GRP box section around the edges of the panel;
- Bolted end fixity, through a steel frame, using HSFG Higher grade M20 bolts;
- Support frame consisting of 300x200x16 box section.

Three panels in total were to be tested. Details of the panel and support arrangement are provided on the design drawings reproduced in Figures8.1 and 8.2.

The test procedure aimed to subject the panels to a 1 bar blast overpressure initially, and then to a standard fire test to achieve an H120 rating.

8.5 Structural Aspects of the Full Scale Test Specifications

8.5.1 General

The large scale blast tests were performed on an approximately 2.5x2.5 m^2 square panel consisting of two thin GRP skins with the HRB insulating core; a 50x50x10 GRP pulltruded box section around the perimeter of the panel. A steel frame (300x200x16 box section) was provided around the panel to mobilise in-plane membrane forces in the panel. Bolted fixity conditions were used so as to represent actual fixing arrangements.

8.5.2 Blast Tests

Displacement measurements were taken at the panel centre. Displacements were also be measured at a point on the panel diagonal mid-way between the panel centre and corner. The displacement transducers were located on the outside of the panel. Peak displacements were expected to be less than 200mm

In order to measure the relative effects of bending and membrane effects on the skins of the panel, two sets of two-dimensional strain gauges were placed on the outer faces of the loaded and unloaded skins of the panel. These gauges were placed in a similar arrangement to that of the displacement transducers but in a different quadrant to avoid clashes between instrumentation.

Since the blast and the fire tests will be carried out at different sites, it was important to ensure damage did not occur to panels subjected to blast testing during transportation prior to the furnace tests.

8.5.3 Fire Tests

The large scale furnace tests were carried out according to appropriate procedures, for example, the Department of Energy Hydrocarbon Fire Test Specification and Procedure, Issue 1 - January 1990 (UK). Each panel was tested for up to the standard 2 hours. An engineering drawing of the furnace support arrangement is shown in figure 8.3.

The furnace temperature time history was controlled to represent the appropriate hydrocarbon fire testing curve. Efforts were made to assess the heat radiation flux due to the flame, the furnace configuration and lining materials.

The basic testing criteria were that during the testing period the average back face temperature should not be more than 139°C above the ambient temperature and no hot spot should be more than 180°C above the ambient temperature. (These criteria are subject to modification by certifying authorities.)