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Legioblock concrete retaining walls

Fire resistance study

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1. Introduction

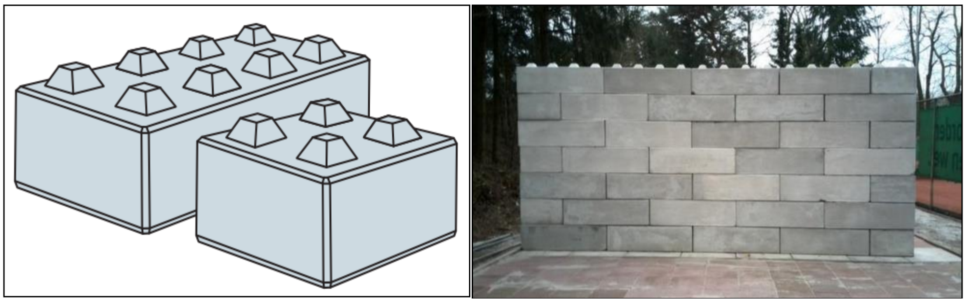
Concrete blocks ‘Legioblock’ are stacked as retaining walls for the storage of flammable materials, like wood and car tyres, in the open air. Given that the fire resistance of the walls is relevant and that fire safety legislation and regulations must be met, a study has been conducted.

2. Product description

2.1 General

The Legioblock is a non-reinforced concrete block with standard dimensions, which can be stacked. The most common basic dimensions of the concrete block are 160 cm x 80 cm x 80 cm, or 160 cm x 80 cm x 40 cm (length x width x height). The blocks interlock to create a fire-resistant and separating retaining wall of 80 cm thickness. Illustration 1 is an impression of Legioblocks stacked in half-brick overlap.

Illustration 1: impression of Legioblocks and application as a separating wall



2.2 Product description and design

2.2.1 *Concrete quality*

Legioblocks are concrete stacking blocks with studs. The material is non-reinforced concrete with a concrete quality of C20/25 to C30/35. Table 1 shows the relevant properties of the concrete.

Table 1: concrete quality specifications

Concrete quality	**Compressive strength**		**Specific density**	**Construction aggregate**	**Vapour diffusion (resistance number)**
	Cylindrical pressure strength	**Cubic pressure strength**		**Gravel grain group**	
C20/25	25 N/mm²	20 N/mm²	2000 kg/m³	16-32 mm (coarse)	8-14
C30/35	35 N/mm²	30 N/mm²	2000 kg/m³	16-32 mm (coarse)	8-14

The product quality is assured through quality certificates (KIWA) and production checks. The concrete quality is achieved after 28 days' hardening time and prepared under ideal conditions (prefabicated). In practice, the sustained average cubic pressure strength is 33 N/mm². The average sustained axial yield strength is 2.2 N/mm².

2.2.2 *Separating wall construction*

Legioblocks are stacked overlapping each other with self-centering studs and holes. Corners and T-connections are made by overlapping and interconnecting the Legioblocks. The edges of the Legioblocks are chamfered 10 mm. The elements connect to each other directly both vertically and horizontally.

2.2.3 *Connections (joints/gaps)*

Legioblocks are stacked on top of each other with matching studs and holes. Despite careful stacking, slit-shaped openings are unavoidable between the stacked blocks, both horizontally and vertically.

The horizontal openings between the blocks stacked on top of each other can be several millimetres wide. The horizontal slit widths are expressed in the net (aerodynamic) aperture of the slit. Based on the dimensions (height and depth) of the slits, it can be concluded that no fire transmission will occur.

The dimension of the vertical slits between the adjacent blocks depends on the evenness of the wall base, and is generally limited to several millimetres. Occasionally, an exceptionally wide gap is unavoidable, up to 30 mm.

Illustration 2: connections of Legioblocks retaining wall with joints and chamfered edges

2.2.4 *Load on the wall*

The stored product exerts forces to the retaining wall. The lateral load perpendicular to the wall has been specified at a maximum of 8 kNm per metre of wall length. This is much less than the friction force from the Legioblock wall weight (normal force).

3. Basic principles

This study was conducted on the basis of theoretical physical fire considerations. The investigation assumed the standards indicated in Chapter 4 and the following data:

- Standard EN 1992-1-2 (Eurocode 2) design and calculation of concrete constructions for fire
- Fire temperature time curves from the standard EN 1991-1-2
- Publication 'spatgedrag van beton bij brand' (spalling behaviour of concrete exposed to fire), Vereniging van Ondernemingen van Betonmortelfabrikanten in Nederland, 2006
- Peutz reporting letter on the fire resistance of Legioblocks dated 10 January 2005
- Tabellarium Fire Safety Engineering, Stichting Kennisbank Bouwfysica, The Netherlands
- Fire Recyclinghof Essen, 26 January 2011
- Fire Kost Bochum, 16 July 2007

4. Assessment framework

4.1 Assessment methods and standards

4.1.1 *Configuration standards*

For assessment and application as a wall with a separating function, the European test standards were used, namely:

- Standard EN 1363-1:2012 Determining fire resistance – General requirements
- Standard EN 1363-2:1999 Determining fire resistance – Alternative and supplementary procedures
- Standard EN 1364-1:2015 Determining the fire resistance of non-load-bearing construction components – Walls
- Standard EN 1365-1:2012/C1:2013 Determining the fire resistance of load-bearing construction components – Walls

4.1.2 *Classification standards*

The European standard EN 13501-2:2016 was used for the classification. For the association with Dutch regulations, the Dutch standard NEN 6069:2011 'Beproeving en klassering van de brandwerendheid van bouwdelen en bouwproducten' (Tests and classification of the fire resistance of construction components and construction products) was also used. The European standard is stricter than the Dutch standard NEN 6069:2011. For this reason, with the application of the European standards, the classification in accordance with the Dutch standard can also be applied directly.

In consultation with the client, for the German classification, the standard DIN EN 13501-2:2016-12 'Klassifizierung von Bauprodukten und Bauarten zu ihrem Brandverhalten - Teil 2: Klassifizierung mit den Ergebnissen aus den Feuerwiderstandsprüfungen.' has been applied.

4.1.3 *Thermal loads*

For the thermal loads, the separating wall was assessed based on the following standardised thermal loads (fire curves):

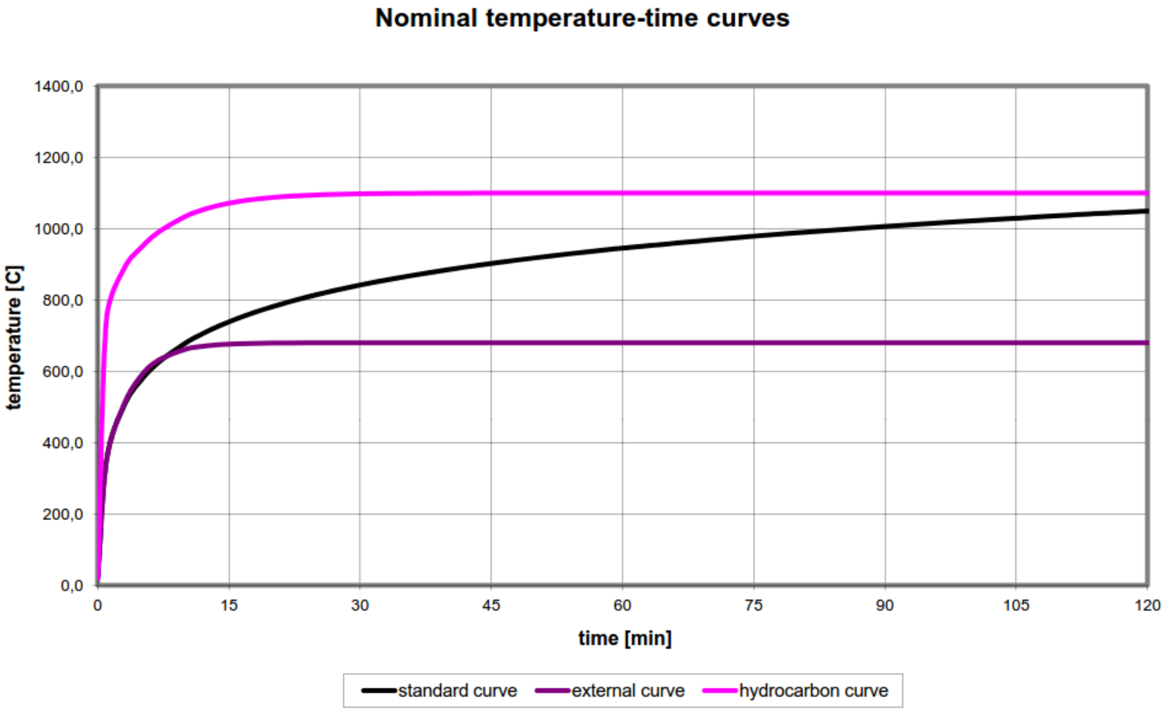
- the standard fire curve (indoor fire)
- external fire curve (outdoor fire)
- hydrocarbon fire curve

Illustration 4 shows the progress of the standardised thermal loads. The assessment was performed taking into account the standard test configuration (testing in the test oven). This test configuration tests a non-loaded separating wall with dimensions (w x h) of 3 m x 3 m.

In positive assessment results (fire duration 240 minutes) with the standard fire curve (indoor fire), it may be suggested that this will also comply in the application of the external fire curve (oudoor fire). For a positive end result, a direct and limited applicability for large wall dimensions also applies.

The external fire curve has a temperature rise from 0 to 30 minutes in the oven, and subsequently the oven temperature remains at 680°C until 240 minutes.
The standard fire curve has an almost identical temperature progress. After 30 minutes the temperature continues to rise gradually, after which it reaches 1153°C after 240 minutes.
The hydrocarbon fire curve has a very rapid temperature rise from 0 to 10 minutes at an oven temperature of 1034°C. This characterises a situation in fire with hazardous materials (hydrocarbon fire), so that internal tensions and characteristic materials behaviour are tested better in this situation. After 10 minutes the oven temperature rises to 1100°C and it remains thus until 240 minutes.

Illustration 3: standardised thermal loads (fire curves)



4.2 Assessment criteria

The following criteria apply for the assessment for classification:

R: Load bearing capacity. The length of time that the relevant structural element is able to carry the nominal load in a normal fire development phase.
E: Integrity. The length of time that the structural element retains its integrity against flames or hot gases in a standard fire.
I: Insulation. The time it takes to produce an increase in temperature on the cold side of the structural element, usually 140 ^{0}C
W: the criterion for thermal insulation associated with the heat radiation

4.2.1 *Load bearing capacity (R)*
The criteria apply in two directions (i <=> o), namely from inside to outside and from outside to inside. The acting load is only in the vertical direction in the form of pressure forces as a consequence of the separating wall's own weight which must retain its required strength and stability.
The fire resistance concerning this criterion is determined at the moment that the construction is thermally loaded, and the moment that the construction is not able to transfer the load with its own weight (normal force) to the base. Under testing, failure may also be assumed in the case of too much or too rapid distortion of the wall. The speed and distortion distance (deflection and axial distortion) are determinants here.

4.2.2 *The criterion for integrity (E)*
Failure for this criterion occurs at the moment that unacceptable openings (e.g. slits, cracks, open joints, holes etc) appear on the unheated side so that:

a) flames are consistently visible for 10 seconds or;
b) at a distance of 5 mm (unheated side) from the opening, cotton pads smoulder or ignite or;
c) the gauges (two steel bars with a diameter of 6 mm) can be passed through the separating construction without force, and are moved forward at least 150 mm, or a 25 mm gauge can pass through an opening.

4.2.3 *Thermal insulation criterion associated with temperature (I) and heat radiation (W)*
The insulation criterion (I) is exceeded once the average temperature on the unheated side exceeds 140°C or the maximum temperature rise exceeds 180°C.

The heat radiation criterion (W) is exceeded once the maximum heat radiation on the unheated side exceeds 15 kW/m² at 1 metre distance.

The heat radiation criterion (W) is only exceeded if the wall has a surface temperature of approx 450°C. This means that if the insulation criterion (I) is fulfilled, the heat radiation criterion (W) is also fulfilled.

5. Investigation and assessment

The application of Legioblocks has been assessed as a wall with a separating function, placed vertically in the open air. The fire resistance occurs in both horizontal directions (inside => outside and outside => inside) and for the three standardised fire curves. The assessment was performed for a fire duration of 240 minutes.

5.1 Load bearing criterion (R)

Determinant for the load bearing criterion are the heating-up speed, the fire duration (240 minutes), the moisture content, the material behaviour of concrete in fire, and the vertical force on the Legioblocks (compression strength). The lowest row of Legioblocks in a wall experiences the greatest compression force. For a wall height of 3 m, this is 75 kN per element ([3.0-0.4] x [0.8 x 1.6 x 2,300 x 9.81]). For safety reasons this assumes a higher specific density (2,300 kg/m³) instead of the value indicated in Table 1 (2,000 kg/m³).

5.1.1 *Assessment of compressive strength*

The pressure force that occurs from the wall's own weight is 0.06 N/mm² per contact surface area of a Legioblock (for a surface area of 1.28 m²). Legioblocks have a characteristic compressive strength of 25 N/mm² to 35 N/mm² at 20°C environmental temperature. In this normal situation, the pressure force is much smaller than the compressive strength.
However, for an internal temperature increase (after approx 200°C) the pressure force of the concrete reduces. Tables are shown in Eurocode 2 with which this reduction can be calculated. For an internal temperature of 1100°C (highest oven temperature for 240 minutes in the case of a hydrocarbon fire curve), the cubic compressive strength is only 1 - 2 percent of the original compressive strength. Thus at least 0.25 N/mm², which still is sufficient to support the pressure force.

5.1.2 *Spalling behaviour and reduced bearing surface*

In the rapid heating of concrete, the moisture present in the concrete is converted into steam, whose volume increases strongly and quickly. This leads to internal stresses (pore pressure) and to cracks and spalling. For a high moisture content and high density, the spalling of the concrete surface has an explosive nature.

The sudden temperature rise only occurs at the concrete surface. Already at several centimetres depth the temperature rise is slow and limited, as a consequence of the heat conduction to the unheated side. Based on the non-stationary heat conduction calculations, this investigation has assumed that spalling can occur up to 0.23 m distance from the wall surface.

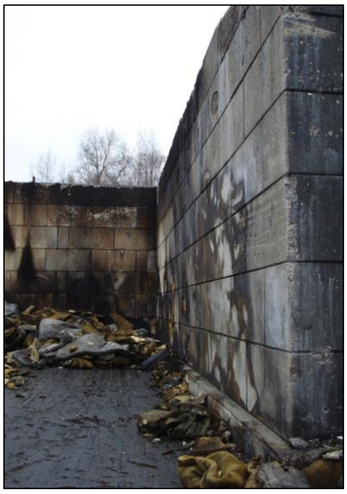
As a consequence of spalling, the contact surface area is reduced. If it is assumed for safety reasons that 0.23 m has succumbed, a load-bearing area remains of 0.8 – 0.23 = 0.57 m width. With this reduced contact surface area, the pressure force that occurs from the wall's own weight is 0.08 N/mm². This is still a factor 3 below the characteristic cubic pressure force under fire conditions of 0.25 N/mm² to 0.35 N/mm².

From the earlier investigation by Peutz (dated 10 January 2005), it is stated on the basis of the Dutch standard NEN 6071 that spalling occurs at a compressive stress of 218 N/mm². This value supports the observation above. The Eurocode 2 (simplified calculation method) assumes that the concrete cross-section that has a higher temperature than 500°C loses its bearing strength, and that concrete below 500°C retains its entire bearing strength.

On this basis Eurocode 2 states that for fire resistance of 240 minutes, a concrete beam must have a reduced width of 280 mm. The Legioblocks amply fulfil this requirement.

In practice (Recyclinghof Essen fire) it appears that during a long fire duration (>240 minutes), spalling has occurred at the chamfered edges. The spalling depth varies around an average of 30 to 50 mm. This is less than the theoretically determined depth of 230 mm. No damage was visible on the unheated side.

Illustration 4: spalling damage



The thermal distortion of the wall is described in Chapter 5.2 and has no significance with regard to the load bearing criterion.

Based on these findings, it has been concluded that damage (‘spalling’) of the non-reinforced concrete and heating with the three standardised fire curves do not lead to failure of the wall with a separating function for a fire duration of 240 minutes. In the worst case, the wall retains at least three times the required strength and stability. The R240 load bearing criterion is amply met. This result permits a vertical wall height up to 8.8 m, with the nominal horizontal load. The calculations were performed without piers. From the aspect of constructive safety, piers can be necessary for high walls, as illustrated below.

5.2 Flame density criterion for integrity associated with the sealing (E)

As horizontal gaps between the concrete blocks are smaller than the vertical gaps (and the fire behaviour of horizontal gaps in general is more favourable), the study has focused on the vertical gaps. Fire transfer through a vertical gap of up to 30 mm is described in further detail below. This takes account of the heat radiation, air movements and air pressure differences arising from a fire.

The most unfavourable combination of circumstances is assumed:
- Thermal distortion
- Wall thickness reduced to 0.6 m as a consequence of spattering

Thermal distortion
During the thermal loading with the three fire curves, the characteristic expansion at time t=240 minutes is a maximum of 1.3 mm per Legioblock. This distortion is distributed evenly across the concrete blocks and is absorbed by the stacking tolerances.

Heat radiation
The vertical gap can offer a 'view' of the fire, from the compartment to be protected. A 30 mm gap produces a view factor of maximum 0.02. Assuming a fire radiation intensity of 100 kW/m^2, the radiation intensity on the 'receiving' side is 0.02 x 100 = 2 kW/m^2. This radiation intensity is so small that fire transfer is excluded.

Air movements
The movements of air, hot fumes and flames through an open gap are determined by the air pressure difference between both sides of the gap. Without wind this pressure difference is determined by the fire: through the gap, air (oxygen) is sucked towards the direction of the fire. Hot smoke does not penetrate to the other side of the retaining wall.

Some 'cold' smoke however, can penetrate to the other side of the retaining wall by wind forces. There is no ignition source here, so no fire can occur.

The situation with fire + flames directly at the retaining wall, with a slit opening directly above the seat of the fire in a strong wind blowing perpendicularly onto the retaining wall, is considered further. The flammable fumes can only permeate to the other side of the retaining wall if the wind pressure on the retaining wall is higher than the thermal pressure. The thermal pressure depends on the height of the seat of the fire + flames (chimney effect). The surrounding buildings and the storage material reduce the wind pressure on the retaining wall (compared to the wind pressure in an open area with wind pressure coefficient 0.8). On balance, only under extreme theoretical conditions (storm precisely perpendicularly onto the retaining wall, small pile of material directly against a high retaining wall) could hot smoke arrive at the other side of the retaining wall. Flames will not permeate through the gap to the other side of the retaining wall.

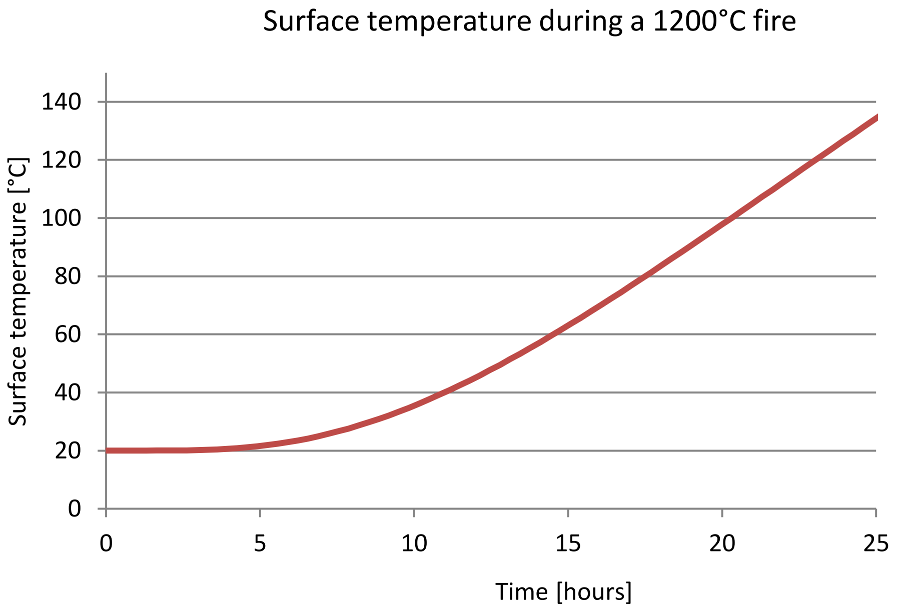
5.3 Thermal insulation criterion associated with temperature (I) and insulation (W)

The hydrocarbon fire curve is relevant for the temperature criterion. Based on the standard EN 13501-2:2008 concerning the fire resistance of concrete, calculations were performed on the temperature distribution in the concrete. The retaining wall was set out schematically as a solid concrete wall, with a temperature of 1200°C on the fire side. Temperature calculations were performed using the finite elements method. The following assumptions were used in the calculations:

- Thermal conductivity of concrete: 2.0 W/mK
- Specific heat: 840 J/kgK
- Heat transfer resistance at the fire side: 0 m^2K/W
- Heat transfer resistance at the other side: 0.20 m^2K/W

The calculated average temperature progress is shown in Illustration 6. It can be seen that the calculated surface temperature on the non-heated side after four hours is less than 25°C. On the non-heated side of the wall the heat radiation is less than 0.2 kW/m^2. Temperature criterion I (140°C average or 180°C maximum) and the radiation criterion W (15 W/m^2) are met during 240 minutes.

Illustration 5: average surface temperature on the non-heated side



6. Application area

The fire resistance of building constructions is generally determined on the basis of fire tests, for example in accordance with standard EN 13501-2:2008. The Legioblock storage situations are substantially more favourable than the standard test situation:

- The thermal exposure of the retaining wall is less severe than the 'standard' fire curves.
- In the fire test the fire area is overpressured; in the open air the fire area is under-pressured as a consequence of the thermally driven air/smoke flows.
- In the fire test cotton pads are used to assess the integrity of the wall. These pads ignite easily when exposed to heat. The storage materials, wood, rubber, fertiliser and the like, ignite less easily, as a consequence of higher heat capacity, moisture content, specific density and chemical composition.
- The favourable behaviour in fire has been confirmed with fires that have occurred over recent years.

For burning rubber, literature refers to the release of oil. Should this in fact be the case, the released oil quantities are small. Oil and extinguishing water could permeate to the other side of the retaining wall. The oil is cooled down and there is no ignition source, so that a fire transfer cannot occur.

The conclusions concerning the fire resistance of the Legioblocks wall with a separating function apply to the dimensions and connections described in Chapter 2. For stacking, the blocks must be interlocked with at least 1 row of studs and must be stacked overlapping. The conclusions are applicable for walls of up to 8.8 metres high.

The fire load may be present up to 1.6 metres below the upper edge of the wall, to prevent fire transfer between compartments. For materials that release flying sparks, supplementary measures must be taken.

7. Conclusion and classification

Based on the investigation, it is concluded that Legioblock walls with a separating function have a fire resistance of 240 minutes in both horizontal directions, in accordance with the standards NEN 6069:2011 and EN 13501-2:2016. This applies within the application area and the limiting conditions that are described in this report.

REI 240 (i⇔o)

Mr C.A.E. (Kees) Rijk

Legioblock retaining walls with a roof

Fire resistance study

Legioblock walls are not only applied in the open air, but also with a roof or covering. The fire conditions, air movements and the pressure differences at the wall differ significantly from the open-air situation. For this reason, supplementary conditions apply with regard to sealing the vertical air gaps between the Legioblocks:

- Situation 1: between the retaining wall and the roof there is an opening of at least 1 m height (around the entire perimeter). The hot fumes can escape through the opening and no sealing provisions are required.
- Situation 2: one side is entirely open (at least 20% of the storage perimeter) up to the level of the highest point of the covering roof. The vertical Legioblock gaps – where they are broader than 5 mm – that are located higher than two-thirds of the average space height are to be sealed.
- Situation 3 (other situations): the vertical gaps – where they are broader than 5 mm – that are located higher than 1 metre above the floor level are to be sealed.

The air gaps can be sealed with mineral wool. Mortar or other fire-resistant sealing materials can also be considered. If the sealing is performed with material other than mineral wool, the sealing must be applied to both sides of the wall.

For all other aspects (i.e. other than the air gaps), the fire resistance regarding the separating function is identical to that in the open air, so that the REI 240 classification can also be assigned here.

Constructional aspects
Generally the roof covering is a steel construction with steel roof paneling. This places a relatively light point load on one Legioblock, which distributes the forces equally along the wall. The specific mechanical forces and the influence on the fire resistance (structural failure) have not been included in this investigation. When applicable, specific constructional calculations must be performed.