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High-Rise Buildings in the Netherlands: Hybrid Structures and Precast Concrete

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Abstract

The emergence of new building materials and new construction technologies has changed the face of the building industry. Structural steel, reinforced and precast concrete are now easily accessible and compete in the construction market. However, joining forces, seeking synergy rather than confrontation, is the emergent trend. The result of this trend is a growing number of hybrid structures in use in everyday building practice. Hybrid or mixed construction with precast concrete means combined use with other structural materials, such as steel, timber, cast-in-situ concrete and glass, for the benefit of the building process at large. In the Netherlands two recent examples of this development are the "Malietoren" office tower, constructed over the motorway entering the city of The Hague, and the 100 m high sloping "Belvedere" office tower in Rotterdam, where the aim of the architect Renzo Piano to create appealing but competitively priced buildings was realised through hybrid construction. The planned concepts, alternatives, final solutions and detailing of these two architecturally appealing buildings are discussed in this paper, to illustrate this new development. A development in which, especially in the Netherlands, precast concrete is playing an important role.

1. Advantages of hybrid construction

Hybrid construction maximises the structural and architectural advantages of combining components made of different materials. To achieve this, it is vital to have good cooperation between the architect the structural engineer, services engineer, manufacturer, supplier and the contractor. Hybrid or mixed construction must be distinguished from "composite" construction where different materials are constructed to act as one structural unit.

In hybrid construction the different materials may work together or independently, but will always provide advantages over the use of a single material. Today in engineering practice, builders and users are discovering that hybrid construction is essential to meet architectural requirements, providing high surface finishes, minimising structural floor depths, achieving better sustainability and ensuring rapid construction, all of which translate into substantial savings and better quality of the end-product. Hybrid construction methods vary considerably with the type of construction and building function. These reflect local trends, environmental and physical conditions, relative material and labour costs and local expertise. The fib-commission 6 -Prefabrication, Working group on Mixed Construction[1] reports the following.

- Currently hybrid construction is being used in more than 50 % of new multi-storey buildings, once the traditional domain of cast-in-situ concrete and structural steelwork. Precast concrete is ideally suited to hybrid construction as it may be readily combined with other materials, such as steel, timber, cast-in-situ concrete, masonry and glass, for the benefit of the building process at large.
- By using precast concrete as the dominant material in hybrid construction, on-site operations are considerably reduced because there is less wet concrete to place, fewer loose reinforcing bars to fix and fewer structural components and formwork to erect. There is also less construction noise and disturbance to local communities. This results in a safer working environment. Prefabricated components also provide working platforms for workers, and this eases the construction process and improves safety.
- Various case studies claim that hybrid construction when compared with traditional systems can save between 10% and 20% construction time.
- Hybrid construction is, by definition, cost effective because it maximises the beneficial structural and architectural advantages of using components made of different materials. The technique requires the cooperation of architects, consulting engineers, manufacturers, suppliers and contractors.
- In some cases client and architectural demands can be satisfied only by using mixed construction techniques.

2. The "Malietoren" office tower, The Hague

The growth human population and its demands for increased living and working space are often in direct conflict with our desire to conserve grasslands, forests

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and natural resources. Multiple use of space for our building activities is one answer to this dilemma.

The “Malietoren” office tower (Figure 1) is a case in point. It is situated over the “Utrechtse Baan” motorway entering the city of The Hague. The building is almost square in plan, 40 m long and 32.2 m wide (Figure 2). The ground floor is designed as an entry and reception area (Figure 3). Above are five car parking floors reached by a spiral ramp cantilevering half way over the motorway on the north face of the building. The sixth and seventh floors are conference facilities while the remaining 13 floors are designed as offices. The building services are concentrated on the top floor of the building, bringing the total height to 74 m. (See the appendix for the construction details).

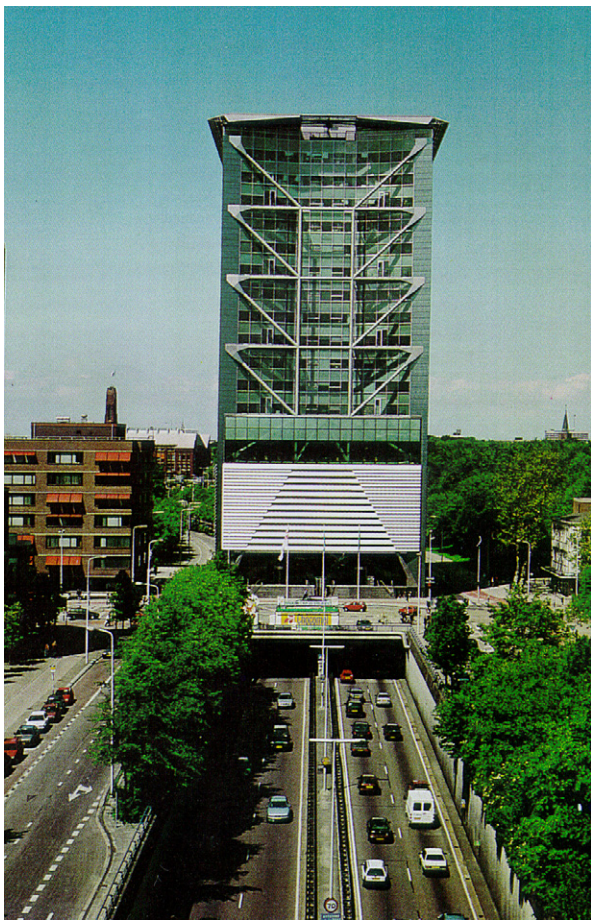


Figure 1. The Malietoren office block

3. The structure

Building over an existing motorway is never easy. The motorway – effectively a watertight reinforced concrete trough sunk into the ground – cannot be closed without causing severe disruption to the life of the city. As a result, it had to be bridged over to prevent any disturbance, including additional loads or penetrations to the trough.

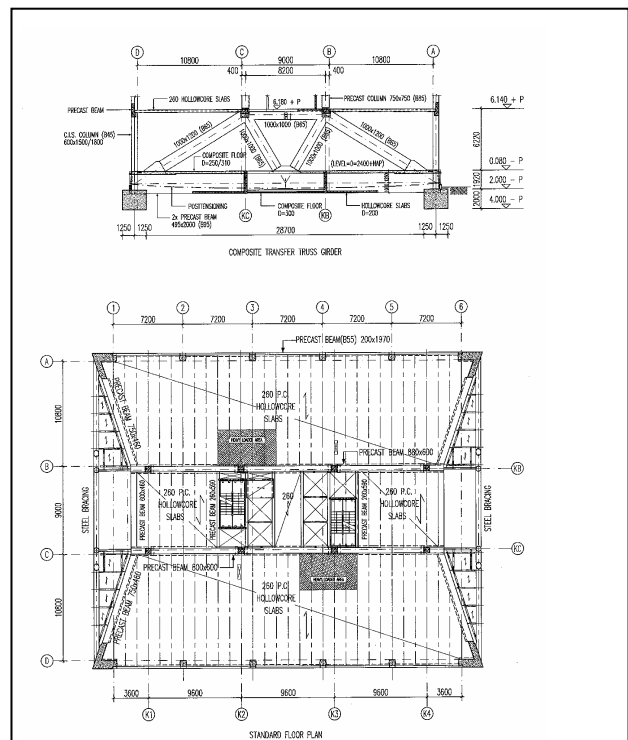


Figure 2. Elevation of truss and plan of building (dimensions in mm)

The optimum solution was to adopt a composite concrete truss transfer structure (Figure 2) with a height of 8.2 m and a span of 32.2 m at the entrance level.

This also satisfied the architectural perception in terms of structural demands and economy. The 2m-deep precast, prestressed and post-tensioned lower chord of the truss was designed to function at the erection stage as a simply supported beam to carry the weight of the ground floor acting as a working area. Being prefabricated, the beams and working floor were placed very quickly (in a single night) (Figure 4). Diagonals and the upper chord were then added in situ concrete B65. The upper floors are precast hollow-core slabs on precast prestressed concrete beams, which are very economical and fast to erect. (Figure 2)



Figure 3. Entrance and reception area

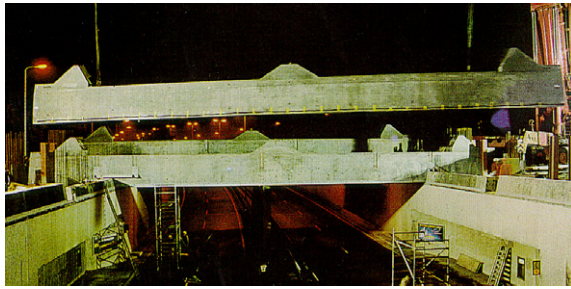


Figure 4. Erection of precast beams

4. Innovation

For the high-strength (B85) two-storey precast concrete columns, an innovative, but simple and cheap, connection (Figure 5) was developed using steel plates and epoxy resin injection resulting in an enhanced speed of erection and a minimum column cross-section area (8% reinforcement). Composite precast concrete façade frames in system lines A and D and structural steel bracings in system lines 1 and 6 (Figure 2) were connected by in-situ concrete corner columns (Figure 6) to form a stabilising façade tube. The result is a high quality environmentally and ecologically friendly building at a very competitive price.

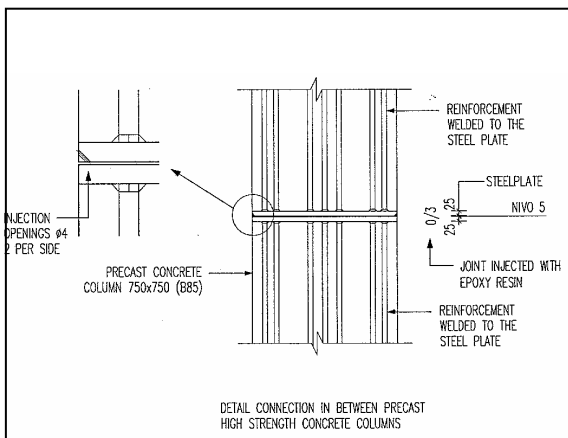


Figure 5. Column-column connection (dimensions in mm)

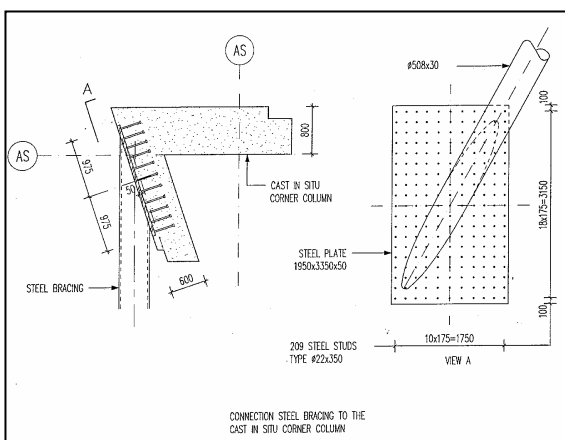


Figure 6. Connection of steel bracing to corner column (dimensions in mm)

5. The “Bélvédere” sloping tower Rotterdam

The old harbours in the centre of Rotterdam have lain idle for a number of years. Today these areas are prime locations for urban development. Wilhelmina pier, the site from which over the past two centuries many European emigrants have boarded ships on their way to America, is one such a location. Situated on the River Maas, it is connected to the city centre by the well-known Erasmus bridge, “the Swan bridge”. Development of high-quality buildings on this location is the aim of the Municipality of Rotterdam and of the designers involved.



Figure 7. Artist's impression

6. The building

The architect Renzo Piano was commissioned by the Real Estate Developer William Properties BV to produce the architectural design. His inspiration was the Erasmus bridge immediately adjacent to the location of the building site. The 100m tall building follows the inclination of the cable stays of the Erasmus Bridge (Figure 7 + 8). The building contains approximately 20000 m² of office space, 5000 m² of retail and commercial space and two levels of underground car parking for approximately 250 cars.

7. The inclination

The 6° inclination of the building, or rather of its eastern façade close to the Erasmus bridge, was the first challenge faced by the structural engineer. The position of the columns (vertical supports), in relation to the inclined side of the building, influences the horizontal forces acting upon of this inclination; that is to say, the

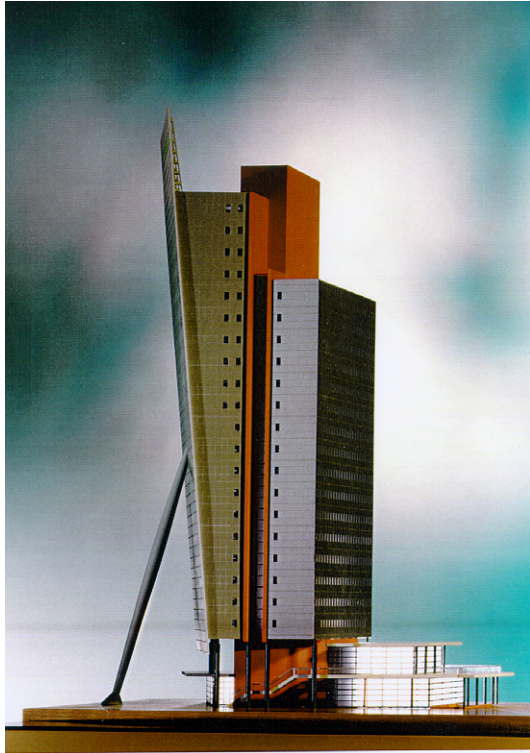


Figure 8. Model of the building

bigger the span, the bigger the vertical floor support reaction to be carried by the inclined side and the bigger the horizontal load caused by this inclination on the stabilising structure (Figure 13). However, even with the optimum position of the columns in the given architectural design, this horizontal force was still too great to be borne by conventional structural means like cores or shear walls only. Being an excellent architect, Renzo Piano was instinctively aware of this problem, and even his first sketches on the back of his cigar box include a reversely inclined compression strut to compensate and support the leaning side of the building (Figure 9).

This synergy of form and structure, combined with Piano's understanding of the different disciplines involved, had huge potential as a powerful architectural and structural concept for this building.

8. Inclined buildings: general concept

Before discussing the structural design of the Belvédère tower it may be interesting to look first at the phenomenon of inclined buildings and the impact of the inclination on the price of the building, depending on the structural scheme which has been chosen.

The following static schemes A, B and C (see fig. 10, 11 & 12) for an inclined building with the top of the building being one-half of the base width "a" out of plumb.

In all three schemes the column-floor connections are hinge connections. The diaphragm action of the floors together with the stabilising elements (cores and/or shear walls) provides the stability of the whole.

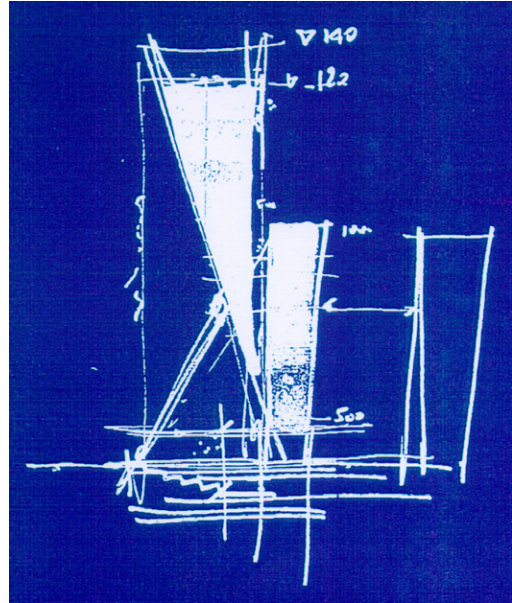


Figure 9. Architect's sketch

Structural scheme A (see Figure 10) shows a design which has floors spanning from one inclined façade to another. The effect of this is that the total weight Q of the whole grid will generate horizontal forces as a function of the inclination of the columns supporting the floors. These horizontal forces in turn will cause moments in the stabilising elements such as cores and shear walls as well as in their foundations. The total moment, which has to be resisted, is

$$M_a = \frac{1}{4}Qa = \frac{1}{2}q_a h^2 \quad (1)$$

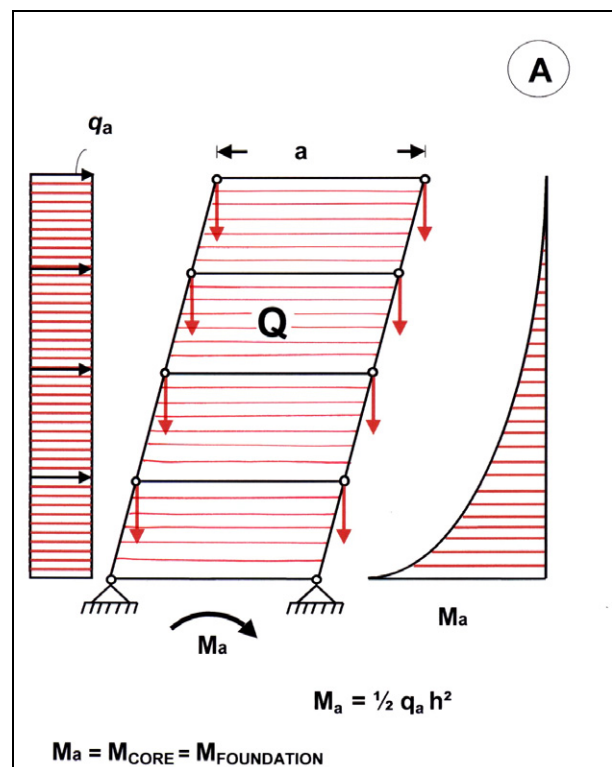


Figure 10. Structural scheme A

Structural scheme B (see Figure 11) shows a scenario where two vertical inner columns have been introduced as close to the façade as possible in order to reduce the reactions of the floors supported by the inclined façades. The smaller the reactions on the inclined façades will be, the smaller the horizontal components of these reactions which in turn will have to be resisted by the stabilising elements. In the given example shown, this results in a considerably reduced moment $M_b = 1/4 M_a$, which again has to be resisted by the stabilising elements as well as by their foundations.

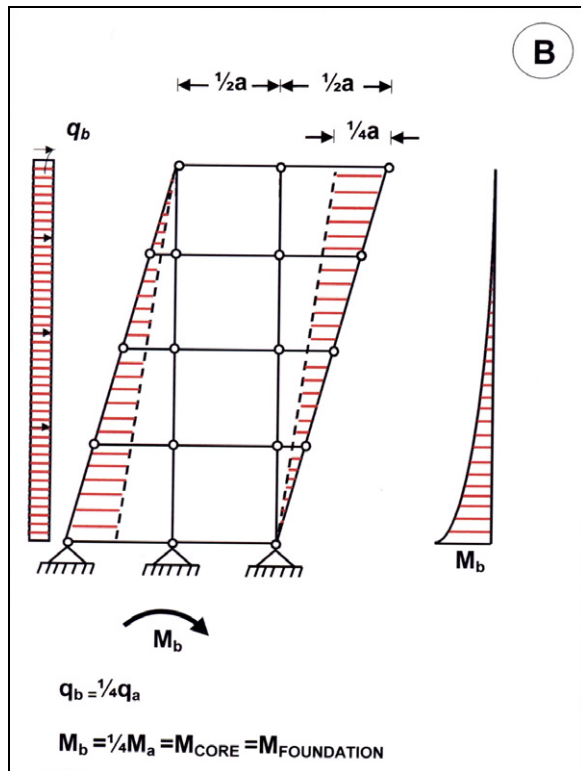


Figure 11. Structural scheme B

Scheme C (see Figure 12) shows a situation which is exactly the same as scheme B, except for the foundation support of the left-hand side façade which is omitted here. The façade is designed as a hanger which transfers the gravity forces first to the top of the building where they meet the vertical column which in turn takes these forces to the foundation. This static scheme has the following consequences:

- The moment M_c due to inclination which has to be taken by the stabilising elements, is only $1/16 M_a$.
- This moment has to be resisted by the stabilising elements and **not** by their foundations as the moment in this scheme at the foundation level is zero.
- As the gravity forces at the left-hand façade are hung up, there is no need of supports. This

gives more freedom to the architect and more column-free space at ground floor level.

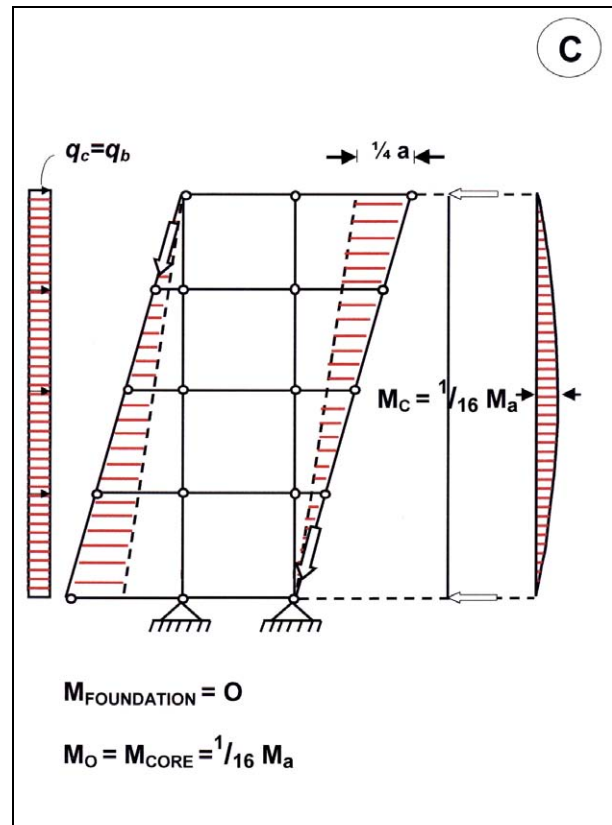


Figure 12. Structural scheme C

It is clear that there will be a significant price variation between a building under scheme A and a building under scheme C, despite the fact that the buildings and their inclination are the same.

9. The static scheme

The reversely inclined strut, depending on its angle of inclination, the magnitude of the vertical load assigned to it, the place where it is attached to the building and the way in which it is designed and detailed to function in the total structural scheme can:

- Compensate for (counterbalance) the horizontal forces caused by inclination of the building (Figure 13)
- Form part of (and function as) an outrigger
- Perform both functions (1) and (2) simultaneously.

An analysis of different structural schemes revealed that the most economical solution was the counter balancing scheme, in combination with structural core for overall stability (Figure 15).

For counter balancing, the central column in the inclined façade does not continue to the foundation but stops at the level +10.5 m above ground level (Figure 16). The total force in this column is transferred to the strut

and together with the tuned angle of the strut, it counterbalances from level +46.55m the influence of the slope of the building.

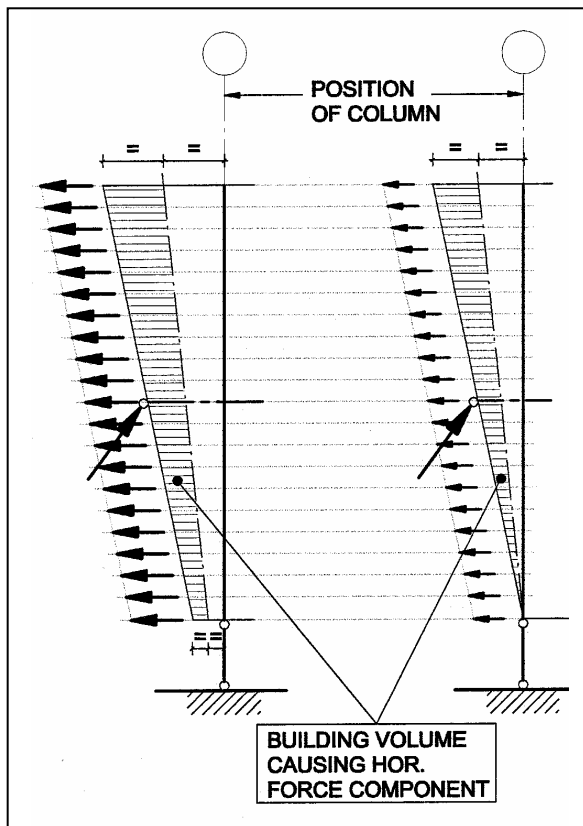


Figure 13. Horizontal forces

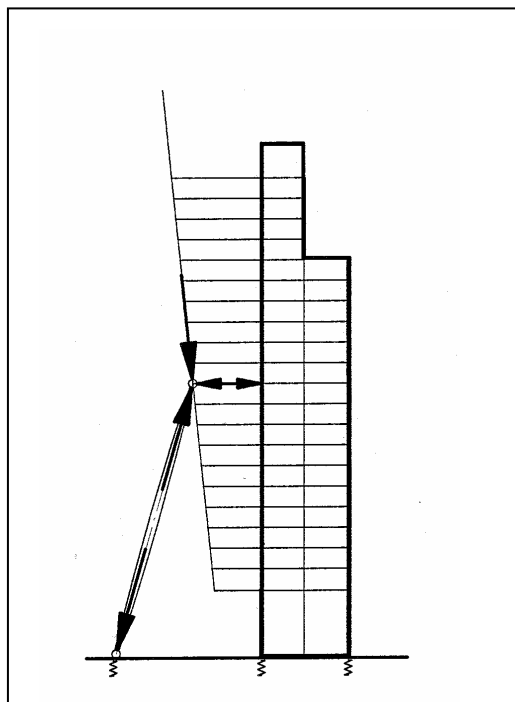


Figure 14. The inclined strut

10. The structure

Once established, this static concept appeared to be a very strong one. Various alternatives with different structural technologies could be realised. From these alternatives two economically equal scenarios were considered and maintained up to the tender stage. Both alternatives were hybrid structures:

- Alternative 1

The vertical section of the building with cast-in-situ core, load bearing façade and precast prestressed hollow core slabs. The inclined part of the building being made of structural steel with composite steel concrete floors.

- Alternative 2

The vertical section of the building with cast-in-situ core, load bearing façade and precast prestressed hollow core slabs. The inclined part of the building being made with two-storey-high precast concrete columns and composite precast concrete beams bearing precast prestressed hollow core slabs.

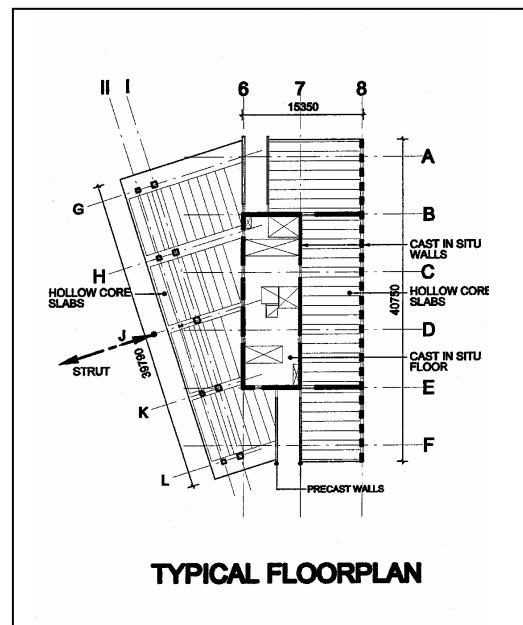


Figure 15. Typical floor plan (dimensions in mm)

In both alternatives the compression strut was designed as a steel/concrete composite member with structural steel tube diameter 800mm at the ends (2000mm in the middle). Due to the required fire resistance, at both ends the strut was filled with concrete over a length of 5 m. The floor at level +46.55m where the horizontal balancing force from the strut is transferred to the structure is designed as a massive 260mm thick cast-in-situ concrete floor.

In the end there appeared to be no difference in price between these two alternatives. However, based on the contractor's experience and preference, alternative 2 was finally chosen (Figures 15 and 16).

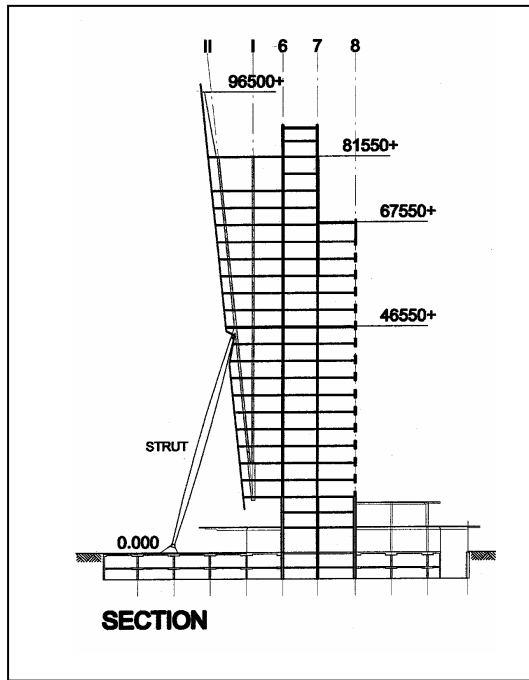


Figure 16. Section (dimensions in mm)

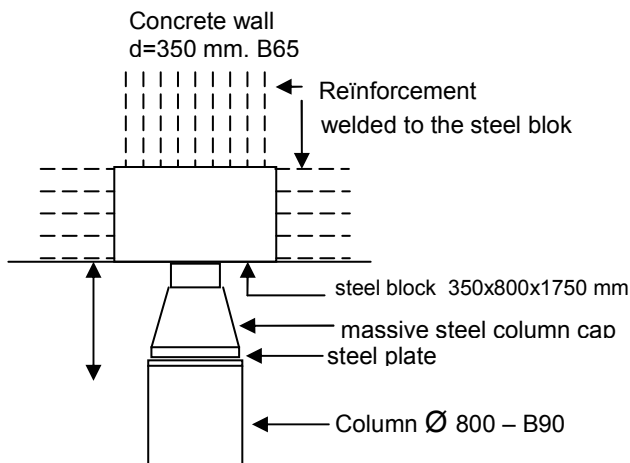


Figure 17. Steel transfer block

In the required architectural design the emphasis was on the strut as an important element, therefore it was very important for the architect that the remaining columns under the building should be visually almost unobtrusive. This was especially so at the top of these columns where the high-rise part of the building transfers its gravity forces to these columns. The solution was a hybrid construction in which columns of diameter 800mm were executed in high-strength concrete grade B90 and provided with massive steel caps, effectively reducing the diameter of the column to only 300mm there, where it meets the upper structure. To transfer the full column force to the 350mm thick grade B65 concrete wall situated above this considerably reduced column section, a massive steel transfer block was introduced into the wall to spread the concentrated force over a sufficient length of the wall (see Figures 17 and 18). Figure 19

shows the building under construction and the appendix gives construction details.



Figure 18. Column detail



Figure 19. Building under construction

Appendix. Construction details for the two buildings

Malietoren office tower, The Hague

Client: Multivastgoed (Real Estate)
Development Gouda, the
Netherlands
Contractor: Wilma Bouw The Hague,
the Netherlands
Architect: Benthem Crouwel Architecten
Amsterdam, The
Netherlands
Structural Engineer: Corsmit Consulting Engineers
Rijswijk, The Netherlands
In cooperation with Ove Arup & Partners, London

"Belvedere" sloping tower, Rotterdam

Client: William Properties BV,
Rotterdam, the Netherlands
Contractor: HBG Rijswijk (ZH),

Architect: the Netherlands
Renzo Piano,
Genova Italy / Paris France
Structural Engineer: Corsmit Consulting Engineers
Rijswijk, the Netherlands

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