

*Architects, structural engineers, and geotechnical engineers have collaborated to design a new type of residence for the Netherlands' second-largest city, one that pairs Rotterdam's tradition of open-air markets with an enormous arch structure that will enable residents to view both the city and the market below. Glass-clad cable net facades at either end of the arch will ensure that the markets remain protected yet inviting.*

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**By Sharon Boranyak**

# ARCHETYPE

**R**OTTERDAM, the second-largest city in the Netherlands, will soon be home to Market Hall, a 40 m tall and 70 m wide arch containing more than 200 apartments as well as restaurants and shops overlooking a 100-stall public market. The 100,000 m<sup>2</sup> structure will integrate the traditional public square concept with a new type of urban residence in a city that can trace its origins back more than 1,100 years. The Rotterdam-based architecture firm MVRDV designed the €175-million (U.S.\$256.4-million) structure for the developer, Provast, of The Hague. DHV B.V., also of Rotterdam, will perform the structural engineering of Market Hall, including one of the deepest excavations in the country's history.

Market Hall's arch of apartments and shops will create a cavernous 117 m long, 43 m wide "hallway" that will link the natural pedestrian flow to and from the city's train station to the main shopping streets in the Laurens district, in the center of Rotterdam. The distinctive hallway will serve as a public square offering sales of produce, meat, and fish by day and lively leisure activities by night, its curved walls and ceiling covered with liquid crystal display (LCD) screens that will offer colorful, ever-changing images. The arch's front and back openings will be covered with flexible suspended glass



facades, giving an open-air feel to the structure even though it will be enclosed. The structure's multilevel basement will feature an underground supermarket and a parking garage.

Market Hall is part of the regeneration of the Laurens district, which takes its name from the Laurenskerk, a 16th-century church nearby and one of the few structures in Rotterdam's center to survive the devastation of World War II. The Laurens district is expecting a building boom, says Esther Hendrix, the public relations and marketing manager for Provast. Many of the area's existing structures, which were built soon after World War II, are poised for redevelopment and reconstruction. For example, before Market Hall's excavation could begin, two primary schools were razed and classes were moved to a former college building that Provast had redeveloped.

Renske van der Stoep, MVRDV's project manager for Market Hall, says the concept was developed during a competition for the design of the project; DHV advised MVRDV and Provast during the competition. MVRDV's founders—Winy Maas,

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Jacob van Rijs, and Nathalie de Vries—led the firm’s winning design team.

During the competition phase, the surrounding area was under development, van der Stoep explains. “Knowing this, we chose an icon that would affect its surroundings instead of follow [them].” She cited Blaak 31—a multilevel office building that is also being developed by Provast and that was designed by another architecture firm and is currently under construction adjacent to Market Hall—as “a good example” of a building influenced by Market Hall’s design. “Market Hall will be an intensified use of space that combines a variety of functions: food, leisure, affordable housing, and parking,” says van der Stoep.

The first two aboveground levels, re-

**Currently under construction in the Dutch city of Rotterdam, Market Hall will house more than 200 apartments, as well as restaurants and shops, in an arched structure that will cover some 100 market stalls. The apartments will have balconies extending beyond the exterior of the arch and windows facing the interior, offering views of the market below and of the liquid crystal display screens that will advertise sellers’ wares. A cable net glass wall at each end of the arch will give an open-air feel to the public market, and entrances in the glazing will admit pedestrians from Rotterdam’s train station and the main shopping streets in the Laurens district, which is in the center of the city.**

ferred to as the ground floor and the +1 level, are designed for public functions, retail (including the produce market stalls), and restaurants and bars. The remaining aboveground floors of the 12-story structure are designed to house 228 apartments. Below the overall structure is a basement of four stories. The first basement level beneath the ground floor (referred to as the –1 level) will house an underground supermarket, and the levels below that will provide 1,200 parking spaces. The parking garage and the apartments have entrances on the sides of the structure, separate from the arch’s main entrances.

Market Hall’s design follows strict Netherlands laws, including recent hygienic requirements that traditional

open-air meat and fish markets be covered and that natural daylight be admitted to certain rooms in homes and apartments. The suspended cable net glass facades covering the main front and back entrances to the arch will provide maximum transparency with minimum structure while meeting these requirements, van der Stoep says.

The apartments will have balconies that extend beyond the outside of the arch, and windows will face the inside of the arch above the market. Rooms that require natural light will be situated along the exterior. Kitchens, dining rooms, and storage areas will be positioned on the inside, establishing a connection to the market. From their windows to the market, residents can check advertisements for daily specials that pop up throughout the day on the LCD screens along the arch's wall, van der Stoep explains.

"I have never seen or heard of any other such arch structure in the world," says Maurice Hermens, a consulting structural engineer for DHV. He says the most challenging aspects of the structural design are the deep excavation in what he calls "thick soup," the construction of the arch structure itself, and the suspended cable net, or "tennis racket," glass wall on the arch entrances.

Hermens says Market Hall's excavation is one of the deepest in the Netherlands. The groundwater level at the site, which is near the North Sea and the river Maas, starts just 2 m below the surface. But with its four stories, the basement is roughly 15 m deep. "The soil on the location is real Dutch soil," says Hermens, "lots of clay, layers of sand, and no bedrock." The soil consists of peat and clay for the first 20 m. This is followed by sand to 30 m, clay (part of the Kedichem Formation) to a depth of 40 to 50 m, and then sand again to approximately 70 m.

Hermens explains that the foundation will be made up of piles that extend into the first layer of sand to withstand pressure and tension forces. The depth of the pile footings will be roughly 27 m for the pressure piles and roughly 29 m for the tension piles. The piles will be of two sizes: one with a 506 mm diameter shaft and a 560 mm diameter footing, the other with a 610 mm shaft and a 710 mm footing. The pressure forces will reach 3,000 kN on the smaller piles and 4,000 kN on the larger ones. The tension forces will reach 750 kN on the smaller



**The structural engineers for the arched structure, DHV B.V., of Rotterdam, refer to the construction technique that will be used to build the arch in two directions, with individual units of floor and wall extending toward each other, as the kissing act.**

piles. The piles will be placed on a 2.5 by 2.5 m grid.

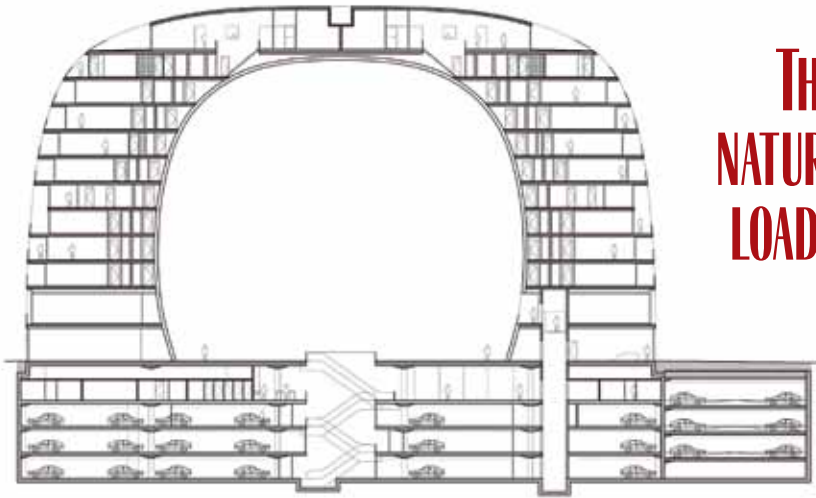
The piles will be driven prior to excavation using conventional pile-driving equipment, Hermens explains. A casing with a footing cover beneath it will be driven into the ground, and a prefabricated-concrete square core that will be 320 by 320 mm for the smaller pressure pile and 380 by 380 mm for the larger pressure pile will be placed inside the casing. The space between the casing and the square core will then be filled with concrete as the casing is drawn upward. As Hermens puts it, "We hang the core with the right length in the casing and fill only the lower part of the casing. This way, we lower costs, and the piles are not a nuisance during excavation. We make only the length [of pile] we need, from fifteen meters deep to the foot of the pile."

Beneath the foundation lies the overconsolidated Kedichem Formation, which could settle by as much as 10 mm for each 10 m of building height. At a height of 40 m, Market Hall will probably undergo settlement of about 40 to 50 mm. What is more, those sections of the structure that do not contain apartments may actually rise a bit—up to 25 mm, Hermens says. "You could call this a floating foundation because the foundation in the sand layer is floating on the Kedichem Formation," he explains.

A wall support method will be used to prevent groundwater intrusion in the excavation, and this is the first time a method of this type has been used in the Netherlands, Hermens notes. Supporting frames consist of steel tubes that would be only temporary in more conventional buildings but here will remain a permanent part of the structure, he says. Circular tubes 1,016 mm in diameter will be used in combination with double sheet-pile walls. The tubes will be driven to a depth of 24 m, whereas

the sheet-pile walls will reach a depth of 17 m. The tubes and sheet-pile walls will be divided into segments measuring 2.6 m in width.

The bottom of the excavation will be closed with what Hermens describes as "underwater concrete." He explains that because of seepage, the excavation will be completed in the wet. A 1.35 m layer of underwater concrete will then be laid to seal the bottom of the excavation. Together with the tension piles, the concrete layer



## THE ARCH SHAPE HAS A NATURAL RESISTANCE TO WIND LOADS, HERMENS EXPLAINS.

Because the ground floor and level +1 will accommodate public functions, concrete columns will be used rather than walls to provide as much open space as possible. In the lower basement levels, columns will be spaced 7.8 m apart to create space for three cars between each

column, and the columns will be placed above one another as much as possible.

The roof will employ the same structural system as the rest of the building, the self-carrying formwork spanning from one side of the structure to the other. However, the top floor and roof slabs will feature prestressed hollow cores to reduce their weight and minimize the need for supports, Hermens says.

Hermens describes the glass facades at either end of the arch structure as the first structural solution of its kind in the Netherlands and “one of the largest in the world.” Each glass facade, which has an area of roughly 45 by 35 m, will be supported by a cable net wall consisting of straight prestressed horizontal and vertical cables. The cables will be 28 mm in diameter and will be spaced 1.5 m apart both horizontally and vertically. The 250 mm thick concrete walls will accommodate the compression forces resulting from the cable net wall’s tension forces. Hermens compares the cables to the strings of a tennis racket and sees the concrete arch around it as the racket’s frame. The “strings of the tennis racket” are able to “resist the ball and even shoot it away,” and the cables in the cable net wall will resist the wind forces on the glass panels, he says.

The glass panels will be fixed to the cables by clamps to obviate the need for holes in the glass and to avoid any stresses that might result from holes. The glazing will be a laminated safety glass designed to keep shards from falling should a pane ever break.

To handle wind loads, the maximum deflection on the glass is  $L/50$ . Given the facade’s length of 35 m, the maximum deflection will thus be 700 mm. The clamps that will hold the glass panels, along with the lamination between the layers that make up the laminated glazing, are designed to allow these deflections. Moreover, at the edges of the arch the glass panels will be suspended from the concrete walls rather than connected to them, and this too will help accommodate deflection.

Market Hall’s construction began in November 2009 and is scheduled for completion in 2014. **CE**

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resists a hydrostatic pressure equivalent to a 13 m high water column. To reduce the depth of the excavation, the pile caps will generally be incorporated into the underwater concrete. After the underwater concrete cures, the excavation will be pumped dry. Finally, a finishing layer of reinforced concrete will be placed to serve as the basement floor of level -4.

Hermens says that DHV often designs housing projects using cast-in-place concrete in an “N-shaped tunnel formwork” and that in such cases the walls and floors are cast together. “In this case we use this system in an innovative way,” he says, creating an arch “like the Romans did, building the two sides toward each other. The individual units of walls and floor are used to build the arch bit by bit. In this project, we call this the kissing act.”

The arch shape has a natural resistance to wind loads, Hermens explains. “Wind loads are quite high here,” he says, reaching 2.5 kN/m<sup>2</sup> at the top of the structure, and wind speeds can reach 35 m/s. The shafts for the elevators, together with the structural walls, provide the stability necessary to resist these loads, he says.

Because the structure will be built almost entirely of concrete, it will be cost effective, he says. The thickness of the walls (250 mm) and floor slabs (270 mm), with a “floating” finishing layer 60 mm thick on top of 20 mm of insulation, efficiently meets the Netherlands’ strict sound insulation regulations for houses and apartments, in addition to a requirement that the structure provide 120 minutes of fire resistance, he adds.

The thickness of the walls and the finishing on the slabs also efficiently handle dead loads, which could reach 9 kN/m<sup>2</sup> on the floors, 6 kN/m<sup>2</sup> on the structural walls, and roughly 1 kN/m<sup>2</sup> on the non-load-bearing facades. The permanent column-supporting frame is incorporated into the structural floor system of level -1. Between the ground floor and level -1, “flag structures” (concrete walls) transfer the column loads horizontally to the exterior.

By its nature the arch will produce tension forces in the ground floor. The flag structures produce pressure forces on the ground floor and tension in the floor below it (-1). But the excavation will produce pressure on the -1 floor. “In this way, [unwanted] tension forces are compensated by other pressure forces, and pressure forces are reduced by tension forces,” Hermens says.