3. Evolution of the manifestation of fixed bridges in The Netherlands as from 1940: Part I

This article gives a survey of the general historical picture, the influential factors on the manifestation and the choice of materials of in particular steel bridges. In chapter 4, part II, a supplementary article, the evolution of various types of steel bridges will be dealt with, such as truss girder bridges, arch bridges, plate girder bridges, box girder bridges and cable stayed bridges.

3.1 General historical picture

3.1.1 Development bridge construction, period before 1945

Due to the ample presence of water in the form of the big shipping routes, transport in The Netherlands until mid 19th century took place mainly over water. Besides, big parts of the country were very marshy, due to their position below sea level. This made them less accessible to traffic by land. The expansion of the road system got an impulse when Napoleon introduced centralized authority of the divided Netherlands. Highways came into existence between cities like The Hague & Haarlem and Utrecht & Apeldoorn. The purpose of these highways was to integrate the annexed area into the French empire. After the French had left The Netherlands in 1813, further plans were made for the layout of a road system. What it looked like is shown in fig. 1.

Until the appearance of the motorcar, traffic by land played a minor part and served only the local need for transportation. When a canal or river had to be crossed, this was done by bridges in case of a small waterway, and by means of ferries in case of bigger waters. Traffic by land did not consist of very heavy vehicles. There were not many of them, and people were not so much in a hurry, like nowadays. That is why the ferries were perfectly satisfactory in those days. The availability of the ferry services was not very well and not always safe. Under misty and stormy weather conditions and in case of ice drift, navigation was practically impossible and wrong manoeuvring could cause the ferry to capsize.

**Fig. 1. The road plan of 1821 for first class roads.**

**Traffic bridges**: On spots where relatively much land traffic crossed the river, the ferry was replaced with a ship bridge, which, as the name suggests, is a combination of a ship and a bridge. This bridging consisted of ships that were laying at a distance of 5 to 8 meters centre to centre, and on top of which a roadway was made. In this way, shipping did not have free passage, but sailing out a number of adjacent ships, thus making an opening, could open the ship bridge. Ship bridges could be constructed cheap and quickly, but the disadvantages were: much maintenance and the necessity to open the bridge even for the smallest vessel. Also, they were vulnerable in case of ice drift and high water levels. Ship bridges over the big rivers were to be found over the Lek near Vianen, over the Rhine near Arnhem and several over the IJssel near Westervoort, Doesburg, Deventer and Zutphen. In the period 1900-1950, fixed traffic bridges replaced all ship bridges. In 1929, a start was made with the construction of the large-scale national highway plan for traffic bridges. The first one was a lattice bridge over the Bergsche Maas near Keizersveer, which was finished in 1931. After that, until the break out of the Second World War, eleven bridges over the big rivers followed. The bridge program, as laid down in the national highway plan of 1927, was completed except for one bridge, when in May 1940 the Germans invaded The Netherlands. In order to stop the march of the German armies, the Dutch army put all bridges out of action. This was done by detonating a load of explosives near the bearings, causing the bridges to crash into the river.

**Railway bridges**: In the 19th century, the trains appeared, first in England and later on at the European continent. In order not to be economically isolated, The Netherlands could not hold aloof, and around 1850 the first train made its appearance in The Netherlands. In the second part of the 19th century, the railway net had been drastically extended and many bridges were built. The first of the 21 big river crossings that were completed in this period was the railway bridge over the IJssel near Westervoort (1856). The Dutch contribution to the accomplishment of all these constructions, for that matter, was small. The designers and building contractors of the greater part of the bridges came from the more industrialised countries around us: France, Germany and the U.K. In the book (in Dutch) "Bridges in The Netherlands" by J. Oosterhoff, these bridges are described [2].

**Period 1940-1945**

During this period, both the Dutch and the Germans worked on the repair of the destroyed bridges. Often this was
not too big a job, because most of the times the substructure was still fully intact, so that placing and repairing of the superstructure sufficed. Before the end of the war, all bridges worth mentioning were fully in service again. However, the liberation of the country led once more to destruction of the bridges. Again, this was caused by the fact that bridges are strategic objects. To hinder the march of the allied forces, this time the Germans destroyed many big and small bridges. As far as the big river crossings are concerned, 16 out of the 21 bridges for railway and road transport were completely destroyed or heavily damaged. The other 5 were not damaged, or only lightly. Besides the big bridges, between 900 and 1000 smaller bridges were destroyed or heavily damaged. The acts of destruction committed by the Germans were clearly heavier than those by the Dutch in 1940.

Fig. 2. Moerdijk Bridge after 1945.

The first big problem the Dutch Railways and the Ministry of Transport were confronted with after 1945 was removal of the destroyed bridges, so that the rivers got cleared for both navigation and discharge of high water and ice. The second problem was repair of the land connections. Although the allied forces had already opened many bridges by means of military emergency bridges, these provisions were temporary and not all cross-rivers were repaired. It was therefore of great importance to establish the connections as soon as possible at those spots where no temporary bridges had been built and traffic had to shift as best it could with a temporary ferry connection. Besides, the bridges that were not proof against ice drift and high water had to be replaced. Immediately after the war it appeared to be impossible to repair the severed connections in a permanent form. This was not only owing to lack of time and material, but particularly to lack of the required steel [3]. There was only a little quantity of steel in stock. Already before the war, material had been ordered for the construction of the Merwede Bridge near Gorinchem. Before the work was started, the war broke out and the material was quickly hidden underground. It could be used after the war, but this and other stocks were far too small. The supply from the rolling mills was also limited because the steel production was not well under way yet. This of course led to very high steel prices. Therefore people had to work with very limited means, reason why temporary solutions were looked for first.

3.1.2 Development bridge building – period after 1945

With the construction of new motorways, including bridges, the thread was taken up again. Mainly with the aid of the Marshall Fund, the works could be financed. First, the works that were stopped in 1940 were resumed. Not until the Road Plan of 1957, the Ministry of Transport presented plans for new roads. This plan did not deviate much from the pre-war plan. However, it focused more on the motorways. This Road Plan now included motorways to all corners of our country. The density of the road net had not changed much. This would change dramatically with the Road Plan of 1968, in which a substantial extension of the road network was mapped out [4]. In this period, mass motorisation began and there was a great need for extension of the road net. In the same period, the Dutch economy was booming, mainly due to the finding of natural gas in the soil of Groningen in 1962. Infrastructure was considered very important and a lot of funds generated by the natural gas profits were invested in this. By the prosperity explosion in other European countries, The Netherlands became increasingly important for the transit of goods and the country established an image of ‘distribution country’, for which a proper infrastructure was of course indispensable.

Traffic bridges

By the huge extension of the road net, also the construction of bridges expanded strongly. This is clearly shown in fig. 3, giving the turnover in bridge building in square metres constructed bridge per 5 years period.

Fig. 3. Number of m² constructed traffic bridges in The Netherlands per 5 years.
For comparison, the number of kilometres constructed motorway is given in fig. 4. Figs. 3 and 4 follow the same pattern of increasing construction activities during the years ‘60 and ‘70 and of a decrease starting in 1980.

**Fig. 4.**
*Number of kilometres motorway constructed in The Netherlands per year.*

In the early eighties, a saturation point is reached and the construction of new roads starts to decrease, entailing a reduction of the turnover in bridge building. A few reasons can be given.

- Most of the works are now finished and the demand for new infrastructure has been met for the greater part.
- The social resistance against the planning of more infrastructures increases. Before the seventies, the structure of a road was welcomed by almost everybody, but after that, more and more protests were heard. The number of square metres asphalt in The Netherlands had increased enormously during the preceding years and the consequences for the landscape and the environment started to become noticeable.
- Coinciding with this is the publication of the report of the Club of Rome, warning against the environmental effects as a consequence of increasing economical growth.
- In the eighties, the western economies arrived in the valley of the recession, so that the financial means for building reduced.

**Railway bridges**

Not many new railway bridges are constructed until around 1975, because the 19th century bridges that were repaired after 1945 as well as a number of military emergency bridges were still functioning satisfactorily. Also during the reconstruction period no major extension of the railway network took place, implying that no new large span bridges for new railways were built. In August 1975, the working group of the Dutch Railways published a report regarding long-term planning for the replacement and doubling of big fixed railway bridges. The inducement for making this report was:

- The big fixed bridges dating back from the period 1860-1900. The increased train loads induced raising the question whether the material, puddle iron, was sufficiently resistant.
- The military emergency bridges that were obviously meant for temporary use would not be able to cope with the increased train traffic.
- The limited capacity of a number of single-track bridges that were situated in double track sections.

This plan was approved. In total, it comprised the replacement of 24 bridges, which meant a great impulse for the construction of railway bridges from 1975 until around 1900.

**Fig. 5.**
*Number of square metres constructed railway bridge in The Netherlands per 5 years.*

3.2 Factors affecting the manifestation of steel bridges

The notion ‘manifestation’ has several gradations. On a big scale level, it refers to choice of material, span and selection of bridge type. On a smaller scale level, details can be focused on, such as choice of joint type, plate thickness, etc. In the period after 1945, the development of steel bridges was affected by a great number of factors, which, interacting with each other, greatly changed the manifestation of bridges. In the course of time, the influence of each of these factors did not remain the same and that is very characteristic for the manifestation of steel bridges. The influencing factors playing a prominent part in this are summarised in table 1.
1. Social factors
- Material cost vs. labour cost
- Aesthetics
- Increase of traffic
- Noise emission
- Durability

2. Maintenance
- Conservation
- Bearings and expansion joints
- Deck layer

3. Traffic load
- Composition of road traffic

4. Material
- Plate thicknesses
- Plate measurements
- Steel types and qualities
- Cable technology

Table 1. Categories of the major influential factors on the manifestation of steel bridges.

Some influential factors (social factors, maintenance, means of connection and competition of steel vs. concrete) will be further elucidated.

3.2.1 Social factors

Material cost versus wages
Until 1950-1955, there was a great scarcity of steel because the steel and rolling mills had to be reconstructed. At the same time, there was a tremendous demand for steel because of the many bridges that had been destroyed. The relation material price/labour cost was extremely high in those days and saving in material was imperative for economic bridge building. Many bridges that were built right after the war were therefore put together from profiles with thin plate thicknesses, provided with a great number of stiffeners to avoid local buckling. The further development shows an increase of labour cost, which progresses many times faster than the rise in material cost. Figure 6 gives the development of the labour cost and material cost from 1950 to 1980. For the period from 1980 onward, this trend continues.

Fig. 6.
Development labour cost versus material cost until 1980 [6].

The influence of the relatively heavily increased labour cost on the manifestation of bridges in general is that a higher material consumption is preferred when it enables economising on the number of actions to be performed during fabrication and mounting.

Aesthetics
As from the thirties onward, the way bridges fit in the landscape started to play a part in the design. In that period, the arch bridge was often applied because this form, in combination with the landscape, was most favourably judged. After the Second World War, this view changed and the bridge was primarily judged on the...
extent to which the traffic passing the bridge was benefited. The bridge should attract the least possible attention. In those days, the arch bridge was even considered a disturbing element that dominated the surroundings too much. A flat, ongoing form was considered much less disturbing in the Dutch landscape. The seventies therefore were the time of the flat bridge. Box girders were often applied, both in steel and in concrete. The economy of building was of primary importance then, which led to standardisation and monotony. The load distribution could not be deduced from the form and the bridges became more and more dull objects to the eye.

From the eighties onward, people reacted more and more critical to the monotony. An increasing need arose to regard the bridge as a town-planning element. In recent years, bridges are designed as conspicuous manifestations. Bridges that not only functional, but also show that they are situated on a special spot. To establish the main form of bridges, architects are called in more often than before. As a consequence, the more striking bridge types are quickly gaining popularity.

3.2.2 Maintenance

Dictated by the higher labour cost and increased environment demands, the maintenance cost of steel bridges versus the cost of site and building went up in course of time. There are various categories of maintenance, the biggest of which is maintenance of conservation. Other maintenance sensitive parts of a bridge are the bearings, expansion joints and the deck system. Within the life of a bridge they sometimes have to be adjusted or replaced more than once. Compared with concrete bridges, this problem plays an important part in steel bridges, due to corrosion and often a lower stiffness, causing more secondary effects. In designing bridges, the maintenance friendliness has to be taken into account. Spots where dirt and liquid can accumulate are to be avoided. Braces used for railway bridges are sensitive to corrosion because nests of dirt are easily formed there. Also bolt and rivet fields are spots subject to dirt accumulation. To make steel permanently resistant, regular maintenance of the conservation cannot be avoided. Every 5 or 10 years the top girder has to be painted and a complete replacement of the entire conservation system is necessary every 20 to 30 years. Much has changed in the way bridges are maintained. The main reason for this is the increased focus on environmental effects, which started in the eighties. The tightened regulation of the working conditions (Occupational Health and Safety Act) also affected the conservation of steel, especially with regard to working conditions in the conservation shed. Until around 1988, no legislation existed with regard to contamination of the surface water when performing work on water, such as (grit) blasting and painting. During these jobs, paint and grit rests get into the surface water. They contain among other things heavy metals (tin, copper) and polycyclic aromatic hydrocarbons (PAHs). When in the early eighties at shipyards spoils were found containing many heavy metals in considerable amounts, the government took action to deal with the root of this problem. In view of this, the Contamination Surface Water Act was called into existence. Since then, a licence is required for possibly contaminating work on or at the water. This licence contains regulations with regard to prevention viz. limitation of emission to the surface water.

The following are of importance for bridges:

- Catching grit and paint emitted when blasting a bridge and limitation of the spray haze when painting these objects. This is possible by ‘wrapping’ the object to be treated. See fig. 7.
- Using less environment unfriendly conservation products

Originally, mostly coal tar containing epoxy coatings were applied to e.g. sluice doors because of their very good anti corrosion qualities. Out of consideration for the environment, these coal tar containing products are hardly used anymore. In the meantime, alternative, less environment hazardous coatings have been developed. Also the Occupational Health and Safety Act demands, made up by production employees working in the paint shed, have been considerably tightened.

![Fig. 7. Maintenance at the bridge near Katerveer, Zwolle.](image)

The vapours that are emitted by applying paint layers must be sucked off to prevent them from being breathed in. With a view to the increased conservation cost, it is increasingly recommendable to simplify the maintenance of a bridge, or, if possible, to make it superfluous. Maintenance friendliness has become an important aspect in the design of bridges. Maintenance starts on the drawing table, one could say. The importance of maintenance also appears from new contracts in which the
contractor is made responsible for the design, the construction and the first maintenance. In the constructive design of a bridge, maintenance can be taken into account in various ways.

3.2.3 Means of connection

In the period 1940-2000, there was a development from rivet joints to bolted joints and welded joints in steel bridges and in steel structures in general. Before the Second World War, almost all joints in bridge building were riveted. Weld joints were made, but only in smaller bridges. For big bridges over the rivers, this type of joint was still regarded insufficiently reliable. For these works, a maximum safety was desired and it was not acceptable to consider them as probes or instructive specimen of a new technique. Welding was a new technique in those days. Already before the development of welding, especially in lattice bridges, a development was going on in reducing the number of rivets in lattice bridges. This can be clearly observed at the diagonals of lattice bridges. The old profile used for this was a double T-profile, composed of a web plate, on which, with the aid of angle steels, the flanges were riveted. The flanges were stiffened against buckling at the ends by riveted angle steel. In the picture on the right side of this page, the section of this profile is given.

To reduce the number of rivets and thereby reduce costs, the double T-profile has been replaced by the so-called open profile; see the figure on the right. Besides saving on rivets, this also meant saving on angle steels, because now the stiffeners of the flanges were used to attach the connecting plates to. That way, the web plate became superfluous. For the connection between the flanges, joint plates were used. Fig. 8 (left) shows the old traffic bridge near Moerdijk, in which this type of diagonal was found. This profile was suitable to take up stress and strain; it was not stiff. That is why it was not applied in railway bridges. In the railway bridge near Moerdijk of 1955 the old double T-profile with web plate was applied.

The Second World War contributed to an accelerated conversion from riveting to welding. An emergency situation existed. Since with welding the production speed of constructing war material was higher, construction shops converted to welding, all under the pressure of a war that had to be won. The Americans led the way, constructing almost 3000 so called Liberty ships that were composed by welding joints. The production of these ships was an early example of quantity production in steel construction. Welding jointed prefabricated standard elements. The production of ships went very fast and when this was well in progress, the 400 ft long ships were built in 5 to 16 days, at the expense of the quality, particularly of the weld joints. The material used was insufficiently resistant to the influences of welding, resulting in brittle crack of weld joints. Due to this, a great number of Liberty ships sank in the northern part of the Atlantic Ocean. The many failures were, however, also valuable lessons for the benefit of the welding technique, also in bridge building. Simultaneously with the rise of welding, riveting dropped out of use around 1955. Skilled labourers, who were able to perform the specialist trade,
were scarce, because due to the increased prosperity, possibilities presented themselves to people to choose other work. Riveting was very hard labour and noisy. It was therefore far from pleasant. Dutch riveters could not be found anymore. Therefore, guest workers from Italy, Spain and Turkey were invited, who were willing to do the work. Ultimately, welding and the prestressed bolt were applied more and more and displaced riveting. The conversion from riveting to welded joints is a very important development for lattice girder bridges, which occurred in railway bridges especially from the sixties onward. Already since the fifties, traffic bridges were constructed and assembled with welded joints. The bridge over the Meuse near Gennip and the Algebra bridge over the Hollandse IJssel at Krimpen are constructed from welded boxes for the upper and lower chord.

![Fig. 9. Development in section erection. Left: riveted open cross section. Right: welded box.](image)

The improvements of the welded box versus the riveted open cross section are:

**More economical manufacturing**
Welding enabled a production speed that was many times higher. With welding, the number of man-hours to compose a box was much lower.

**Closed section**
The open section had an open bottom because the inside of the profile had to be accessible for mounting the rivets. Only in case of very large profiles - big enough to provide access to a man to put the dolly on the head of the rivet - a closed box was possible. The use of welds enabled the box to be produced completely closed. On each corner, a weld joint could be made on the exterior of the box, between web plate and flange.

![Fig.10. Profiles upper and lower chord of lattice bridge over the Meuse at Gennip.](image)

The great advantage of the closed section of the welded box is that the interior is not exposed to atmospheric conditions and therefore does not have to be conserved, or at least less heavily. Further, birds could not build their nests inside the box, which was the case with open sections and shortened the life. Also, connecting the cross girders rigidly, could use the torsion stiffness of the box profile. The first welded profiles were those of the upper and lower chord of the traffic bridge over the Meuse near Gennip (1955). The form of these profiles is derived from those of the riveted open sections, as shown in fig. 10. During manufacturing it appeared that this geometry was less suitable for the welded version, because the profiles, due to their asymmetrical form, distorted considerably during welding. In bridge building, welding has become by far the most applied jointing method. Welding appeared to be the most economical connection, which, in proportion to the improvement of the steel quality and the welding technique, pushed the use of prestressed bolts aside. The advantages that were obvious in the welded joints were the following:

- **Quicker production and automation, giving a saving in man hours**
- **The much simpler joint detail, without welding plates, angle steels and many rivets**
- **The smooth steel surface near the welded joint, which can be painted quicker and better, and does not form a spot where dirt and liquid can accumulate**
- **Avoidance of weakening by rivet holes**
- **Greater design possibilities. A plate girder, for instance, ongoing over several supporting joints, can be made with a high web height at the intermediate supports.**
- **Lower self-weight of the structure. No connecting angle steels and strips are required.**
- **Better working conditions. Riveting is notoriously very tiring and noisy.**

### 3.2.4 Competition steel versus concrete

**Material price/cost price:** Of course the development of the material prices affects the volumes of the materials and concrete applied. However, there is not a great difference in increase in steel prices and concrete prices. In the early days of prestressed concrete in The Netherlands, in many cases the cost price of a concrete and a steel version was established at the moment of putting out the contract. After around 1980 this was not customary anymore because it was known that for the range of most spans, a steel bridge is about 25% more expensive than...
a concrete bridge.

**Self-weight:** Since the time large span bridges were built, steel has been the most suitable material for large spans that could not be realised in concrete. The development of concrete, however, has been quite impressive and with this material, spans up to 300 metres can be easily realised. By applying suspension cables the bridge can even be larger. The restricting factor for the span length of concrete bridges still is the self-weight. For the greater part, the total construction time determines the total cost of site and building. More and more construction methods will appear that enables the realisation of a complete bridge within a short period of time. The self-weight will play a big part in this. When a high construction speed is very much desirable, then steel lends itself well to the purpose. By the increase of the hoisting capacity in the workshops, ever bigger and heavier sections are assembled in the workshops and then transported to the building site over water (by barge). For the major part, the developments in the production facilities are owing to the fact that since around 1970 Dutch steel constructors made their way to the market of offshore constructions. The working conditions at the sites of offshore constructions, on the open sea, that are highly dependent on the weather conditions, can be called right down bad. To improve efficiency of this type of constructions, it is necessary to manufacture and assemble bigger sections and to transport these to the building site in their entirety. The consequence was that bigger workshops were built and that the hoisting capacity was increased. Also, heavier means of transportation were developed. The bridge building industry benefited from this by increasing sizes of parts to be mounted. Composite roadway sections and parts of main girders as well as completely composed bridges could now be mounted (see figs. 11 and 12). In case of a comparable concrete bridge, this method would not be a feasible solution, due to the higher self-weight.

![Fig. 11. Installation of a bridge section with uitbouwwagen; Ewijk.](image1)

![Fig. 12. Assembling of main girders Dintelnaven railway bridge.](image2)

**Construction depth:** Where bridges in the Dutch landscape are concerned, the construction height plays an important part. In contrast with utility construction, with the concept of 'construction height' is meant: the difference in height between the topside of the roadway floor (rails, viz. asphalt) and the bottom of the (main girder) of the bridge. The elevated position of the bridge must be taken up in the vertical alignment of the road, implying that a big embankment or long approaching bridges are required to reach a bridge at elevated height. Especially for railway traffic, a low construction height is important in connection with the small allowable maximum slope. Nowadays, the general opinion is: *achieving a minimum on construction depth results into a minimum on total costs. This is especially the case for concrete bridges and concrete viaducts.*

**Substructure and approaching bridges in concrete:** The substructure of big traffic bridges, regardless of the choice of material for the superstructure, is always made in concrete. Also the approaching bridges are made in concrete since the emergence, around 1960, of prestressed prefabricated girders. Because part of the project is already realised in concrete, sometimes the decision is made to complete the entire project in concrete. In some cases a contractor has a concrete and a steel department, but this is not often the case. Most contractors work either with concrete or with steel, not both.

**Temperature influences:** By the low mass of steel bridges compared to concrete bridges and the heating up speed viz. cooling down speed, problems are apt to appear more often with steel bridges, due to the (uneven) expansion and by slipperiness of the roadway during frost.

**Fatigue life:** More problems due to fatigue damage are to be expected with steel bridges than with concrete
bridges. There are two reasons for this. In the first place, with steel, the ratio between stresses caused by variable loads and stresses caused by self-weight is higher, causing the effect of stress variations to become more noticeable. Secondly, steel bridges have many welded joints, where notches and residual stresses occur. Concrete bridges have thick, massive sections, in which no sudden shifts occur. This keeps the geometric stress range small.

3. Material choice for bridges

3.3.1 Traffic bridges

Following is a survey of the development of the choice of materials in bridge building in the period 1940-2000. To obtain the data of the bridges, the DISK file of the Ministry has been used. It gives concise data, such as length, width, etc. of most of the big traffic bridges in The Netherlands. For major bridges that were not constructed by order of the Ministry, like a few in Rotterdam, information was extracted from magazine articles. Further, the restriction was made that bridges with a total length of the construction smaller than 30 metres are not included. To show the development in the choice of materials, the bridges from the data file are grouped in categories of length and main span. The arrangement in span categories is as follows:

- Bridges with a main span smaller than 30m
- Bridges with a main span between 30 and 50m
- Bridges with a main span between 50 and 100m
- Bridges with a main span between 100 and 200m
- Bridges with a main span exceeding 200m

Material choice for traffic bridges < 30 m

For bridges with a main span of less than 30 metres, concrete is very predominant. Steel plate girder bridges only appear shortly after the war and in some incidental cases. For reinforced concrete plate or girder bridges, these short spans could easily be realised and at lower cost than in steel. The many fly-overs over the highways, which also fall in this span category, were realised in concrete. Therefore, there was a good market for concrete in this span category, enabling quantity-produced manufacture for these bridges. This reduced the construction cost. With the prestressed concrete, applied from around 1952 onward for prefabricated girders, the position of concrete was even more consolidated. With prestressed prefabricated girders, lower construction heights sufficed. Moreover, mounting was simplified.

Material choice for traffic bridges 30 - 50 m

Until 1960, bridges with a slightly bigger span (between 30 and 50 metres) are constructed mainly in steel. Around this time, the application of prestressed concrete was started in The Netherlands and the market in concrete boomed. A second explanation for the increase of the use of concrete is that starting 1950 the concrete centres were a rising industry. This meant a substantial improvement of the availability of concrete at any location. Prior to the era of the concrete centres, a concrete factory had to be erected near every bridge building project to supply the necessary concrete. The transport of concrete by road in mixers did not exist yet. From the moment this was possible, it was attractive, also for smaller projects, to construct in concrete. The use of steel is slowly reduced, until it has decreased to almost zero in 1975. Apart from a steel-concrete fly-over over the highway A12 near Zoetermeer, steel is not used anymore for the relatively short main spans of 30-50 metres. The improvements in concrete manufacture mentioned above and the increase in spans that can be realised with prestressed concrete, are the bases of this development. The existing steel bridges in this span category are mostly stiffened bar arch bridges, but a conversion to plate ridge bridges is observed. The first concrete bridges with this span were arch bridges with low situated roadways. These are reconstructed.
bridges over the Twenthe canal, so there is no question of a new type of bridge here. By the end of the fifties, for a span of 33 m a box girder in prestressed concrete is used, and later on also larger spans bridges were constructed by prestressed concrete.

Material choice traffic bridges 50 - 100 m

Compared with the previous graph of the category main spans between 30 and 50 metres, in the category 50 - 100 metres a shift is obvious from the emergence of concrete and a less rapid reduction of the number of bridges that is made in steel. Here, the rise of concrete can be partly ascribed to the increased application of prestressed concrete. The construction of the bridge over the Meuse at Roermond in 1961 is an important step in the development of prestressed concrete in The Netherlands. Still, more important is the introduction, in the mid sixties, of a new building method for concrete. The method, originating from Germany, was applied in The Netherlands at a bridge over the Meuse and the Juliana canal near Wessem, which was finished in 1966 and had a total length of 506 metres and a main span of 100 metres. This construction method appeared to be very attractive and has made a major contribution toward the improvement of the position of the material concrete in bridge building for the bigger spans. The peak in the construction of concrete bridges around 1970 is to be ascribed to this. Eight out of the eleven bridges were built in concrete. As far as steel bridges are concerned, many bridge types occur for these spans. A trend can be observed from arch bridges to truss girder bridges and finally plate girder bridges. Until around 1970, many tied arch bridges with stiffening girder existed. The first steel cable stayed bridge is built in 1968: the Harmsen bridge in the Rotterdam harbour area. It had a span of 109 metres. The first steel-concrete bridge with a span of more than 60 metres constructed in The Netherlands was built over the Meuse in Venlo in 1957. Further application of steel-concrete in bridges, however, did not take place for bridges with main spans between 50 and 100 metres.

Material choice for traffic bridges 100 - 200 m

The choice of material for the main spans between 100 and 200 metres also shows a conversion from steel to concrete. The left part of the graph shows that for these big spans only steel was applied. From the late sixties onward, the selection of concrete is on the rise. In this period, a number of box girder bridges are built using the cantilever concept without scaffolding. The greater part of the concrete bridges that were built later, are box girder bridges. For this span, the cable-stayed bridge appears. Also for spans exceeding 200 metres, for that matter. The latter was the case with the bridge over the Bergsche Maas near Heusden, constructed in 1990. In steel bridges, many different types of bridges occur: truss bridges, plate girder bridges, stiffened arch bridges and cable stayed bridges. The peak, from 1965 to 1975, also shows the rise of the steel-concrete bridge. These are the steel-concrete bridges that were built over the Schelde-Rijn canal.

Material choice for traffic bridges > 200 m

For main spans exceeding 200 metres, mainly steel bridges are applied in The Netherlands. There is one bridge with a span of more than 200 metres that was realised in concrete. That is the Waal bridge near Tiel, a cable stayed bridge with a span of 267 metres. Prior to 1964 there were no bridges with such a big span at all. In the period after that, there are not many of them, because there is not much need for bridges of that size in The Netherlands. The first bridge of this large span is the Van Brienenoord bridge, a steel arch bridge with a span of 287 m, constructed in 1964. This bridge was never surpassed in
The Netherlands, apart from the second Van Brienenoord bridge, which was constructed beside it in 1989. This one, also an arch bridge, has a span of 295 metres. The choice for an arch bridge is rather remarkable, because in that era the cable stayed bridge was mostly selected for these spans. From an aesthetic point of view an arch bridge was chosen. The last arch bridge, built prior to the second Van Brienenoord bridge, was the bridge over the Beneden Merwede near Dordrecht (span 203 m). After that, in all cases a cable-stayed bridge was chosen instead of an arch bridge. Large span cable stayed bridges constructed in The Netherlands, as from 1970 are the following:

- Waal bridge near Ewijk (1975) with 270 m span over the summer bed
- Waal bridge near Tiel (1975) in concrete with a span of 267 m
- Willems bridge over the New Meuse in Rotterdam (1980) with a span of 260 m
- Second cross-river over the IJssel near Kampen (1983) with a span of 193 m
- Erasmus bridge over the New Meuse in Rotterdam (1996) with a span of 284 m.

3.3.2 Railway bridges

Prestressed concrete was also applied in bridges and fly-overs for railways, be it less than in traffic bridges. The lesser use of concrete in railway bridges is caused by the fact that concrete (box) girders with a high positioned roadway, much in use in concrete bridges, have a very high construction height. Although the span of prestressed concrete railway bridges has increased, steel is selected for spans larger than about 60 m. When prestressed concrete appeared in the fifties, we see more and more concrete railway fly-overs. See fig. 13, made with the aid of data from the Dutch Railways.

When from 1976 onward the construction of large span railway bridges is booming because many older bridges must be replaced, and also a doubling of the railways must take place, concrete is selected for the approaching bridges. The span of the prestressed concrete girders for railway bridges increased because in this case it was determined by the existing supporting points where in the past the steel truss girder bridges (with 30-60 m span) were supported. The first bridge with concrete approaches was the bridge over the IJssel near Zutphen. The approach bridge construction, consisting of six spans, is realised in prestressed concrete with spans of 33 m. Another bridge where concrete approach bridges were applied is the bridge over the Waal near Nijmegen (1978). The span at these bridges was 57.50 m. The bridge over the Lek near Culemburg was replaced in 1980; also prestressed concrete girders replaced the steel approach bridges of 60 m span. The choice of material for railway bridges with spans larger than 60 m is still steel, although for the bridging over the Hollands Diep near Moerdijk a design has been made for a concrete bridge with spans of 100 metres. This design was not carried out after all, and a steel-concrete bridge with a steel girder box as main girder was selected instead.

From 2000 onwards nearly all large span railway bridges are constructed using a concrete deck and a steel main supporting structure. The course on composite bridges gives detailed information on composite bridges.

REFERENCES

[5] Rijkswaterstaat ’50 jaar overbrugd’