Half-Century Experience with Precast Reinforced-Concrete Box Sections for Culverts and Storm Drains in the Netherlands

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ABSTRACT

Because of the typical geographical and hydrological situation in the Netherlands, a complex system of water level control has been established. Under varying aggressive conditions, there are tens of thousands of culverts and other structures that make up this system. For more than half a century most of these culverts have been constructed in precast reinforced-concrete box sections. On the basis on practical experience, the real service life, even under severe conditions, amply meets the design service life. In this paper these conditions, and the achievement in manufacturing strong and durable concrete sections, are described.

In contrast to definable and established problems that can be solved by calculations and tests, one can generally give only theoretical and quantitative reflections on durability problems. To quantify the factors that cause corrosion, it is best to consider what happens in practice. In this paper the observations of the past 50 years on concrete box sections under different conditions are described; it has resulted in the manufacture of strong and durable elements.

WATER LEVEL CONTROL IN THE NETHERLANDS

The Netherlands, better known as Holland, is a small country in the delta of the rivers Rhine and Meuse. A large area of the country is situated below sea level, so the country is protected by dikes against water from the sea and rivers (see Figure 1). For many centuries the Dutch have lived and worked here; taming and controlling the water by an ingenious water control system, performed by thousands of kilometers of canals and tens of thousands of culverts, weirs, and other structures.

The country encounters much seepage from the sea, rivers, and lakes, and it has a yearly precipitation of 800 mm. This water is discharged by windmills, diesel engines, and electric pumping stations. If all the pumps were to stop, about 50 percent of the country would slowly disappear under water.

CULVERTS AND STORM SEWERS

The canals are characteristically wide and shallow, with a flat inclination of the side slopes. All canals are crossed by a dense network of roads, so tens of thousands of culverts and bridges are required. The width of the structure should be chosen such that the cross-sectional area of flow keeps

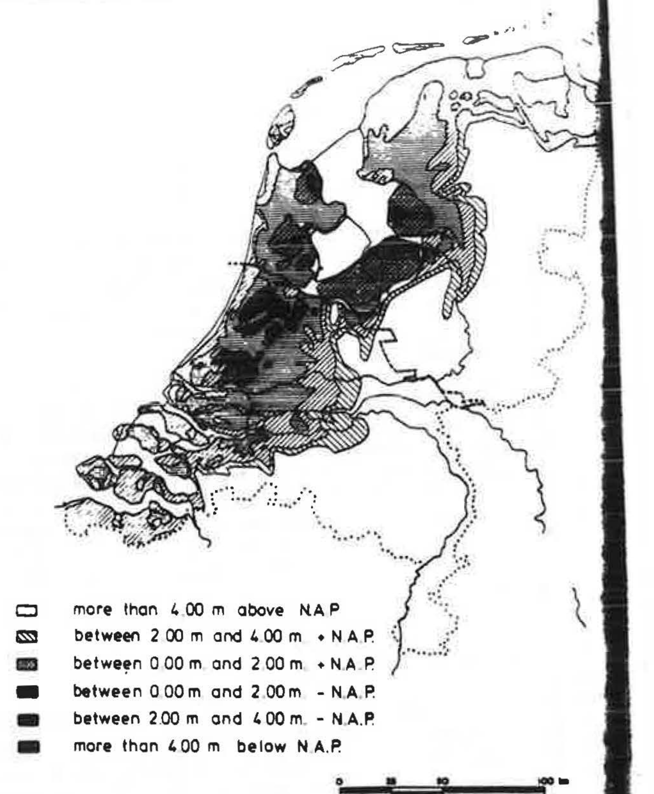

FIGURE 1 Elevation levels in the Netherlands.

within the wetted cross section of the canal, an consequently wide rectangular culverts are most pref erable (see Figure 2). It is clear that all parts o the structures must function satisfactorily through out their service life, and therefore only time tested, durable products are acceptable.

Since the 1930s most of these culverts and man storm sewers have been built of reinforced-concrete box sections because their design is simple, flex ible, and economic; the construction period i short; they are made with strong and durable mate rial; and they are easy to remove and to reuse Also, wide experience has been obtained for severa other applications of these reinforced-concrete box sections, such as collecting sewers, effluent re taining basins, and tunnels.

PRINCIPAL AGGRESSIVE FACTORS

Although Holland is only a small country, ther many differences in groundwater and subsoil condi tions that can be detrimental to varying degrees although in fact only a small proportion of the cul

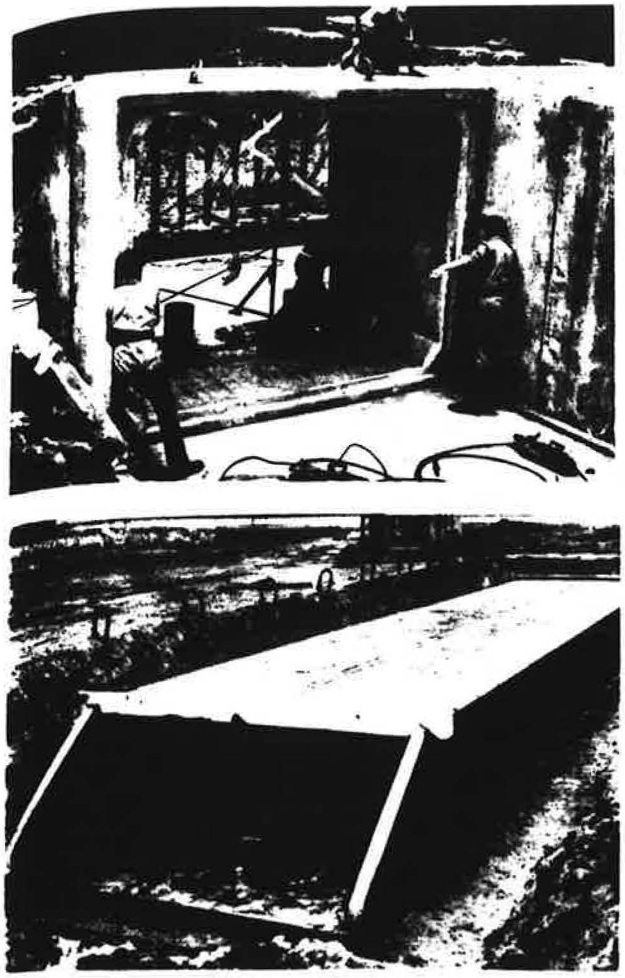

FIGURE 2 Precast reinforced-concrete box sections.

verts are exposed to serious attack. The specific chemical and physical factors that can be aggressive to concrete culvert sections, which account for practically all of the possible durability problems, are acidic soil and groundwater, soft natural groundwater, sulfates, chlorides, freeze-thaw action, and erosion.

Acidic Soil and Groundwater

Concrete is basically comprised of chemicals, and therefore it is attacked by acids. Concrete is not resistant to strong solutions of most acids, and weaker solutions will attack the exposed surface more slowly.

In peat soils humus and other acids are found. Humic acid is a term applied to any of several weak organic acids produced in the decay of vegetation. Peaty water that contains free CO_2 is particularly aggressive to concrete because of leakage from cement. These conditions are found in some places in the Netherlands, but there has never been any rate of deterioration of the sections caused by this aspect, not even when there is replenishment of the acidic groundwater.

Soft Natural Groundwater

Groundwater draining from sandy soils is usually free from dissolved salts but may nevertheless be acidic in nature because of its carbonic acid content, which is derived from carbon dioxide in the atmosphere. It has been demonstrated that this nearly pure water can be corrosive to concrete. Such carbonic acid waters, with a pH of 7 and containing small amounts of dissolved calcium bicarbonate, may be seriously destructive to concrete especially when there is a slow permanent groundwater flow, because such waters can still dissolve calcium carbonate.

In the higher parts in the southeast of the Netherlands there is natural groundwater flow that requires special attention to cast-in-place concrete, although any attack to the box sections has never been found.

Sulfates

Some soils contain sulfates, and consequently the groundwater in such a soil is a sulfate solution. These soils are potentially harmful to concrete. The attack is usually accompanied by expansion caused by the formation of one or more solid reaction products that have a volume greater than that of the solids entering into the concrete. Such reactions lead to expansion and damage of the concrete.

In the Netherlands there are also areas with acid sulfate soils. These are mainly the so-called yellow mottles "cat-clays" that occur in the lake bottom soils of inland polders. However, the attack of box culvert sections in this type of soil is unknown.

Chlorides

The most significant aggressive action of chloride is corrosion of steel in reinforced concrete. Concrete normally provides a high degree of protection against corrosion for embedded steel, but the passivity may be lost if aggressive elements such as chloride are induced. Sometimes problems occur with bridge decks, which result from the use of de-icing chemicals.

In some places the groundwater contains more than 2,000 parts per million (ppm) of chloride because of seepage in the coastal area. No reports or evidence of chloride-induced erosion damage to reinforced-concrete box sections have been received.

Freeze-Thaw Action

Freeze-thaw damage is caused by water penetrating into concrete interstices and freezing, which generates stresses and disrupts the concrete if it does not have sufficient strength to resist these stresses. Atmospheric exposure usually accompanies freeze-thaw action, which complicates the situation. Thus thermal stresses and evaporative surfaces with concentration effects and crystallization of various soluble salts in the pore structure could combine to provide an accelerated weathering effect.

Normally, a buried culvert is not exposed to freeze-thaw or thermal stresses, but these stresses can affect the head walls or wing walls. When this has occurred the performance and resistance to such action has been excellent because of the high quality of the concrete.

Erosion

Erosion is deterioration brought about by the abrasive action of fluids or solids in motion. Erosion by itself does not create problems for concrete culverts in the Netherlands. Velocities up to 5 m/sec do not create any abrasion effects.

PRODUCTION OF CONCRETE BOX SECTIONS

Standards

The concrete box sections are designed according to well-known design codes and according to the Dutch standard NEN 7031. Other than the standards specified in ASTM C 789, the combinations of span and rise are strongly restricted.

In the Netherlands there are only three standard load classes instead of the long tables of several design earth covers in C 789. In the Dutch standard there are no special requirements for durability, probably because durability problems have never been encountered.

Manufacture

Because of the requirements of durability, the concrete has to be as dense as possible; therefore the sections are manufactured by a dry-cast system in an industrial manner. Typically in this system the mold is removed immediately after casting and compaction. The dry cast uses low frequency but high amplitude vibration to densely compact the dry mix in the mold. The amount of cement is approximately 350 kg/m^3, and the water/cement ratio is approximately 0.32.

All production is carried out under close supervision. Procedures for controlling quality are used throughout every phase of manufacture; it starts with the raw materials and finishes when the sections leave the plant.

PRODUCTION FACTORS THAT INFLUENCE DURABILITY

To manufacture a durable concrete product, the following factors are important: making dense concrete, allowing adequate curing after casting, having sufficient concrete cover on reinforcement, and applying portland blast furnace cement.

Dense Concrete

In the dry-cast system the concrete has to be as dry as possible and has to be compacted to make fast demolding possible and to maintain the dimensions within the very close tolerances required.

Adequate Curing After Casting

The dry casting must be followed by curing under suitable conditions during the early stages of hardening. During curing the hydration of cement takes place in the water-filled capillaries until the pores have been filled to the desired extent. Complete filling by the products of hydration leads to low permeability. The sections are therefore covered by plastic sheets, which function as a kiln during the first day. The next day the concrete can be cured in the open air, provided that temperatures are high enough. A simple sprinkler can be used to provide a moist environment.

After 1 week the culvert sections are strong enough to withstand their design load. A greater part of the hydration has also occurred, therefore, for normal conditions, the durability is sufficient. Only under severe conditions is it advisable not expose the sections until after a minimum of 28 hardening time.

Sufficient Concrete Cover on Reinforcement

The minimum concrete cover on the reinforcement 20 mm. This minimum cover represents a balance structural efficiency, crack control, and durab ity. In both the Dutch and the ASTM specificat the steel stress is limited to ensure that the cr width is not greater than 0.2 mm.

Application of Portland Blast Furnace Cement

Portland blast furnace cement with a minimum content of at least 65 percent is used. This type cement also resists sulfate, and concrete made blast furnace cement has also a low Cl diffus coefficient:

1. Ordinary portland cement = 44 x 10^{-9} cm^2/sec
2. High sulfate-resistant cement = 100 x 10 cm^2/sec, and
3. Portland blast furnace cement = 4 x 10 cm^2/sec.

JOINTS

The weakest link in the chain of sections is joint. Originally joints were formed as male female ends, and the space between them was fil with mortar or bituminous mastic. The durability this kind of joint is inferior to the concret therefore regular inspection and maintenance necessary.

Since 1970 most box sections have been with a rubber sealing, thus assuring a watert joint. The applied styrene butadiene rubber is wel known and has already been used in sewer systems a long time. When this type of sealing is used, durability of the total culvert or sewer is gu anteed.

CONCLUSIONS

Concrete in precast reinforced box sections has nificantly superior durability characteristics concrete used in cast-in-place structures. Based 50 years of experience, culverts and storm se built of reinforced-concrete box sections, es cially when applied with a styrene butadiene rub sealing, even under aggressive conditions, fulf an important and reliable function in the comp water level control system in the Netherla Because of this excellent experience, these box s tions are now also used for collecting sewers, fluent retaining basins, and tunnels under emba ments.

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The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

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The following acronyms are used without definition in Record papers:

AASHO	**American Association of State Highway Officials**
AASHTO	**American Association of State Highway and Transportation Officials (formerly AASHO)**
ASCE	**American Society of Civil Engineers**
ASME	**American Society of Mechanical Engineers**
ASTM	**American Society for Testing and Materials**
FAA	**Federal Aviation Administration**
FHWA	**Federal Highway Administration**
FRA	**Federal Railroad Administration**
IEEE	**Institute of Electrical and Electronics Engineers**
ITE	**Institute of Transportation Engineers**
NCHRP	**National Cooperative Highway Research Program**
NCTRP	**National Cooperative Transit Research and Development Program**
NHTSA	**National Highway Traffic Safety Administration**
SAE	**Society of Automotive Engineers**
TRB	**Transportation Research Board**
UMTA	**Urban Mass Transportation Administration**