The use of timber in hydraulic structures

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ABSTRACT

Throughout the Netherlands, timber is used in a wide variety of road and hydraulic structures. As with other structures, timber for these applications need to be strength graded and attention is given to structural grading of soft- and hardwoods and the relationship with some Eurocode 5 design rules and requirements from EN standards. Attention will be given to risks for biological degradation. Some applications require more specific rules that do not always deal with structural safety, but with user requirements such as structural decking and handrails for bridges. A special standard with rules for a number of applications has been developed, varying from requirements for timber decking to large poles. A number of timber structures will be highlighted in this paper. This concerns sheet pile walls, lock gates, bridges and some more special structures such as guard rails and road sign structures.

INTRODUCTION

From the total investments in buildings and structures, about 30% is spent in road and hydraulic works. In the Netherlands alone, that adds up to a yearly expenditure form mostly governmental agencies of more than 20 Bn. Euros. This covers structural applications such as bridges, sheet pile walls, lock gates, mooring structures, etc. All structures have life spans of about 40 years or more and need to be designed according to design standards such as EN 1990 and EN 1995. Only in specific cases other design lifetimes are required. As an example, for guard rails the design lifetime is roughly 20 – 24 years whereas for road bridges the design lifetime is about 80 years. Road bridges in timber however are virtually non-existent in the Netherlands, but many bridges exist where timber beams are placed on a steel grid as a road deck with a deck layer on top. Such beams are typically loaded in shear.

WOOD QUALITY

Grading for strength class assignment

Generally, grading of timber focuses on the determination of three parameters: bending strength, modulus of elasticity and density. The latter is generally considered as important for joints and connections, since the embedding strength of timber is based on the characteristic density. However, an analysis of the relationship between board density and joint strength reveals the correlation is about zero. A number of tests have been performed. In the first series of tests, 4 meter long boards were measured for density and boards were matched in the sense that boards with similar density were paired for use as side and middle members of joints respectively. In this way, series of joints could be manufactured with almost the same density for all three members. Of course, in this case, differences in density with a single specimen containing three wood pieces occur because of 'within member density' variations.

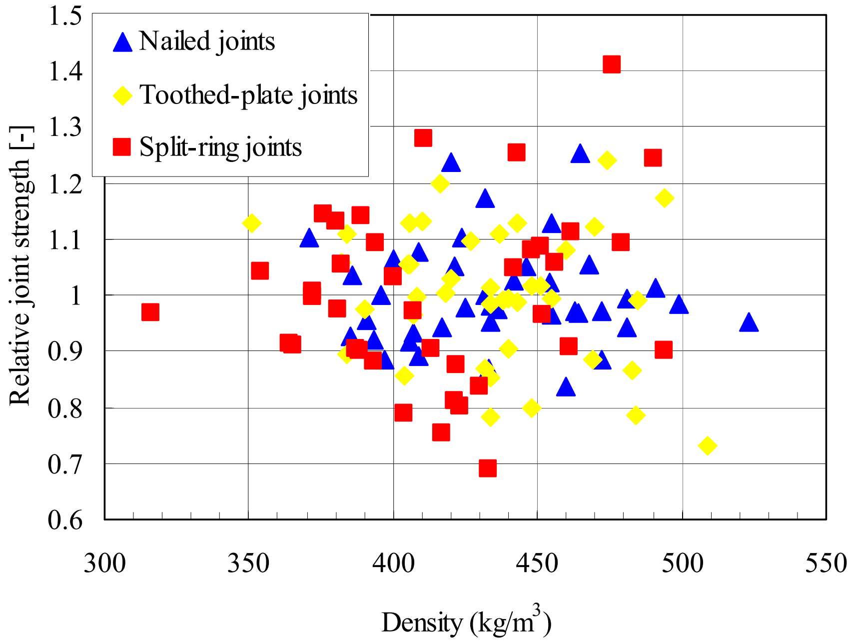

Figure 1: Relationship between density and joint strength

It is however practice that density of full boards are measured because beforehand it cannot be guaranteed which part of the board will be used for the joint.

The results are shown for three different joint types, namely nailed, toothed-plate and split-ring joints. The latter is a commonly used connector type for hydraulic structures. It is clear from Fig. 1 that no relationship exists between the density of boards and the final strength of a manufactured joint.

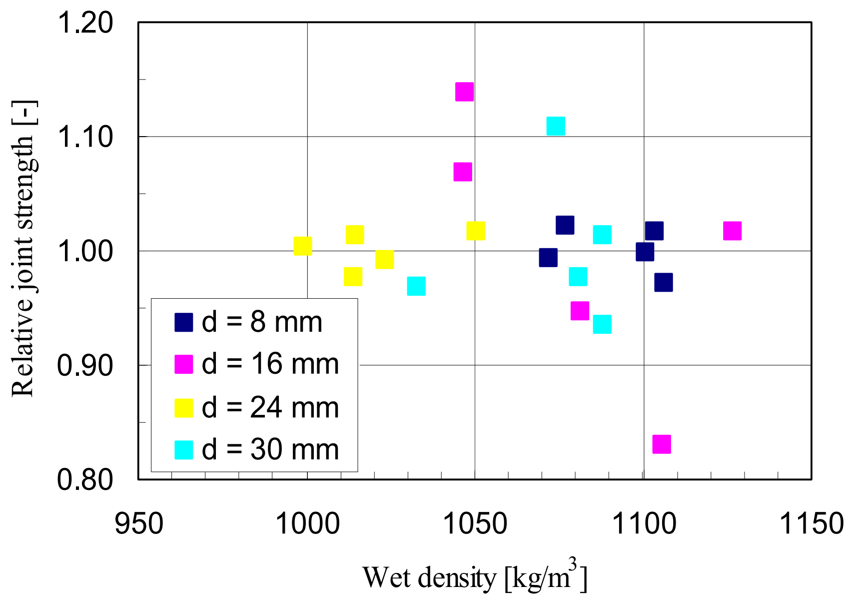

Figure 2: Influence of wet density on the relative strength of azobé double shear joints

For tropical hardwoods the picture does not change. In Fig. 2 the relative strengths of azobé joints are shown for dowel diameters between 8 and 24 mm. Again, no influence of density on the strength can be found. In this case, the three member densities were averaged, but not matched. Fig. 1 and 2 show that standard regulations for grading on density clearly do not have an effect on the load carrying capacity of joints. Of course, when looked at the density in the range from 300 to 1100 kg/m^3, there is a big influence on the load carrying capacity.

Grading for specific applications

For many hydraulic applications specific timber grading rules have been developed, in order to be able to create suitable structures. A number of examples will be given. Sheet pile walls are structures where relative slender boards are used that are loaded in flatwise bending. A typical board may have dimension of 80 x 300 x 6000 mm, giving a length/thickness ratio of 75. (This is not the span to depth ratio). Widths may vary between 150 and 300 mm. In this case all boards have a tongue and groove with a maximum size of the tongue being 24 mm, see Fig. 3. In this case, the generally accepted allowable spring, 12 mm per 2m' board length, cannot be applied. Installation of the sheet pile wall by vibration becomes impossible when the boards do not fit together over the full length of 6 meters. As a consequence, for this specific application the accepted allowable spring is maximised at 8 mm over the full length of the boards.

Figure 3: Tongue and groove profile of sheet pile wall boards

For hydraulic structures, these kinds of requirements have led to the development of a specific standard for timber for hydraulic applications: NEN 5493: Quality requirements for hardwoods in road construction works, hydraulic engineering works and other structural applications. This standard identifies 8 different applications classes for hardwoods, ranging from decking to heavy piles both rectangular and round. For strength classification, the most important parameter is grain deviation, which for most applications is limited to 1:10.

ROAD AND HYDRAULIC APPLICATIONS: HAZARDS FOR DURABILITY

Traditionally, with regard to material properties, timber is classified in durability classes. Normally, four to five durability classes (depending on the location, Europe has five, Australia has four) are distinguished from very durable to non-durable. This system is used to classify the resistance against fungi of the heartwood of the species. The sapwood of species is never durable, so depending on the type of tree, sawn timber products may still have

Figure 4: Shipworm

some sapwood and for outdoor applications, generally the amount of allowable sapwood needs to be restricted. Depending on the final application, some sapwood may be accepted as long as it is exposed to less severe conditions than traditional ground/water contact. The natural durability is a classification obtained from a so called ‘graveyard test’ (EN 460 Natural durability of solid wood - Guide to the durability requirements for wood to be used in hazard classes). Small poles of 50 x 50 mm^2 are placed in the ground and the time (years) is determined until the pole is easily broken by a small impact load. The results of such tests are dependent on the terrain on which the test is performed, but generally the classification tends to give a natural durability of species that can be helpful in the selection process for road and hydraulic applications. However, due to variations in local conditions (soil, temperature, humidity, impact test, etc.) the classification given below is indicative and local results of similar tests may differ.

For use in saltwater there is the risk of marine borers. This requires special attention because not all species from the very durable class are resistant against marine borers. As a consequence, resistance of species against marine borers has been given its own classification, from durable (D), moderately durable (M) and susceptible/slightly durable (S). Actual classification and performance depends however on the location and the related climate. two types of marine borers are common almost around the world: shipworm, Fig. 1,(Teredo spp. / Bankia spp.,) and gribble, Fig. 2 (Limnoria spp.). The risk for marine borers is influenced by water temperature (minimal 5°C) and salt level (minimal 7%). In addition, the pollution plays a role. In polluted areas there is a lower risk of infestation, but with the current recovery of most polluted rivers and estuaries, the risk of marine borer attack is on the increase. The typical decay pattern of a shipworm is difficult to discover, since the entrance holes are small, whereas the member can be completely ruined internally, see Fig. 5. The decay pattern of gribble attack is easier to recognize. Generally, the wood is eaten from the outside to the inside and the piles are cut in two, see Fig. 6.

Figure 5: Decay pattern of shipworm

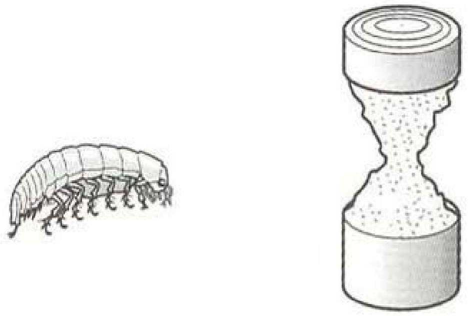

Figure 6: Gribble and decay

If species are used that are not naturally durable for the intended use, the timber shall be chemically treated with preservatives. Wherever timber can obtain moisture contents above 20% for prolonged periods, this is necessary. For many applications it is important, the treatment takes place after the members are made to length and the holes for fasteners and connections are drilled. In this way, also the areas around the fasteners are treated. Otherwise, untreated parts of the members may become exposed when the structure is in place, with rapid degradation as a result. This holds especially for large glued laminated members for instance that are difficult to replace when the structure is in-service. An example of large creosoted glued laminated timber members is shown in Fig. 7, taken during the construction period of the Flisa road bridge in Norway. For environmental reasons however, treated timber is (unofficially) banned in most places.

Figure 7: Truss connection of creosoted glulam in the Flisa roadbridge, Norway

Besides the natural durability, it is important for the material selection process in which climatic conditions the structure will be placed. In Table 1 an overview is given of application classes, ranging from dry indoor to wet outdoor in a marine environment.

The climatic conditions influence the choice of material (wood species, treatment, level of prefabrication, etc.), but also influence the design calculations, as the climatic conditions influence the material properties in terms of strength and stiffness.

Table 1: Relationship between exposure threads and structure types

Hazard class	Characterisation	Wetting	Approximate wood moisture content	Type of structure
Hazard class 1	timber is in an indoor (heated) climate and fully protected from direct weather and wetting.	Permanently dry	yearly average around 12%, maximum 20%	Indoor climate, floors, purlins
Hazard class 2	timber is under a roof, not exposed to direct wetting.	Occasionally wet	≈yearly average around 16%, maximum over 20%	Roof elements, unheated covered elements.
Hazard class 3	not covered and not in ground contact	Regular exposure to moist	≈16-20%	Facades, uncovered roofs
Hazard class 4	ground contact, fresh water	Permanent exposure to ground or fresh water	over 20%	Poles and piles, sheet pile walls, playgrounds
Hazard class 5	salt water	Permanent exposure to salt water	saturated	Water works in harbours, coastal areas

For application in ground contact or water contact, timber with a natural durability of Class 1 or 2 has to be selected. Alternatively, a preservative treatment may lead to a similar resistance. As a help for the designer in EN 460, a cross reference table has been given where the hazard class is given on the one hand and on the other hand guidance is given about the required species in terms of durability and/or preservative treatment.

HYDRAULIC STRUCTURES

Sheet pile walls

Along canals and waterways, thousands of kilometres of load bearing sheet pile walls are installed. These walls can be made of timber boards up to 8 meters long, but generally the longest board length is around 6 meters. An example of a sheet pile wall during the construction stage is shown in Fig. 8 and 9. The upperside of the wall is generally fixed by an anchor in the soil. The structural system and bending moment line is shown in Fig. 10. Both chemically treated pine as well as tropical hardwood is used. A specific character of the boards is that they are coupled by means of a tongue and groove system, allowing load sharing between boards. For this application, special load sharing factors have been derived. Whereas Eurocode 5 specifies a loand sharing factor of k_{ls} = 1.1, for sheet pile walls this factor has been determined at 1.33 and 1.15 for pine and tropical hardwoods respectively. These values are higher that the one given in EC5 because of the plastic behaviour of timber in compression in saturated conditions. This allows for much more plasticity and thus load transfer between boards in a sheet pile wall application. The load sharing for pine walls is higher that for tropical hardwood walls because of the larger variability in material properties. Pine walls are normally made of ungraded material (assumed to be at least C16/C18) material.

Figure 8: Placement of a sheet pile wall by means of vibration.

Figure 9: Tie rods for anchor plates

Figure 10: Seeker profile

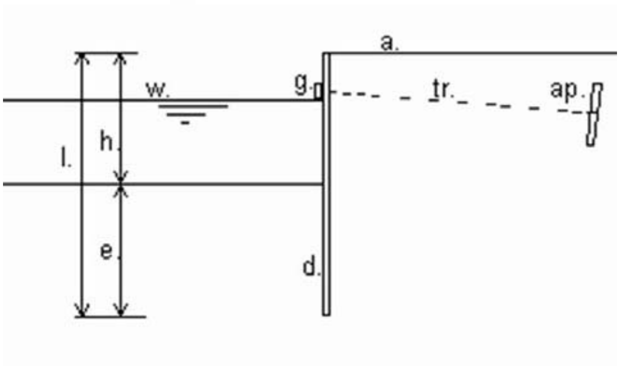

Figure 11: Structural design model of a sheet pile wall

Lock gates

Lock gates are generally made of steel or timber, depending on the size of the doors, Fig. 12. Timber lock gates are heavy structures, with timber sizes of head and heel post often reaching more than 300 x 300 mm^2. Even though the structure itself is quite simple in its form, the gates are complex engineered systems. A top view of the gate shows how the forces are transferred to the foundation.

Figure 12: Lock gate seen from bottom of lock chamber

In closed condition, no water may flow from the side with high water to the side with low water. Therefore, the structure is made in such a way that the load is transferred over the full length of the heel post (achterhar 30 x 35 in Fig. 13) of the gate. This heel post normally has a low density stop plate (usually treated pine) attached to transfer the force to the lock gate walls by means of contact stresses (compression perpendicular to the grain) and at the same time close the gap between gate and lock chamber. A technical drawing of a wooden lock gate is shown in Fig. 13. [Leusen, 1974] Normally, the shear deformations in the plane of the door are avoided by the combination of a steel tension bar and diagonal timber boards.

A special type of lock gates is the wing gate, see Fig. 15 to 17. This is a lock gate that can open and close against high water (HW). A series of tubes allows the water pressure to act on the longer of the two doors in the casing. The doors have a width ratio of 5/6th. The principle was invented by Jan Blanken, working for the state between 1808 and 1826 during Napoleon's era.

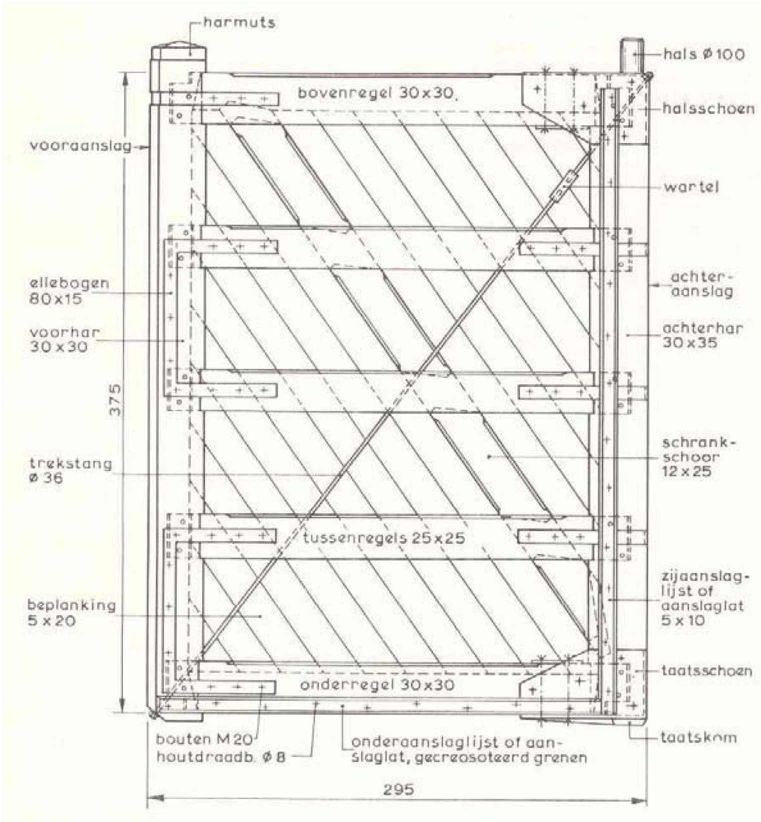

Figure 13: Technical drawing of a lock gate

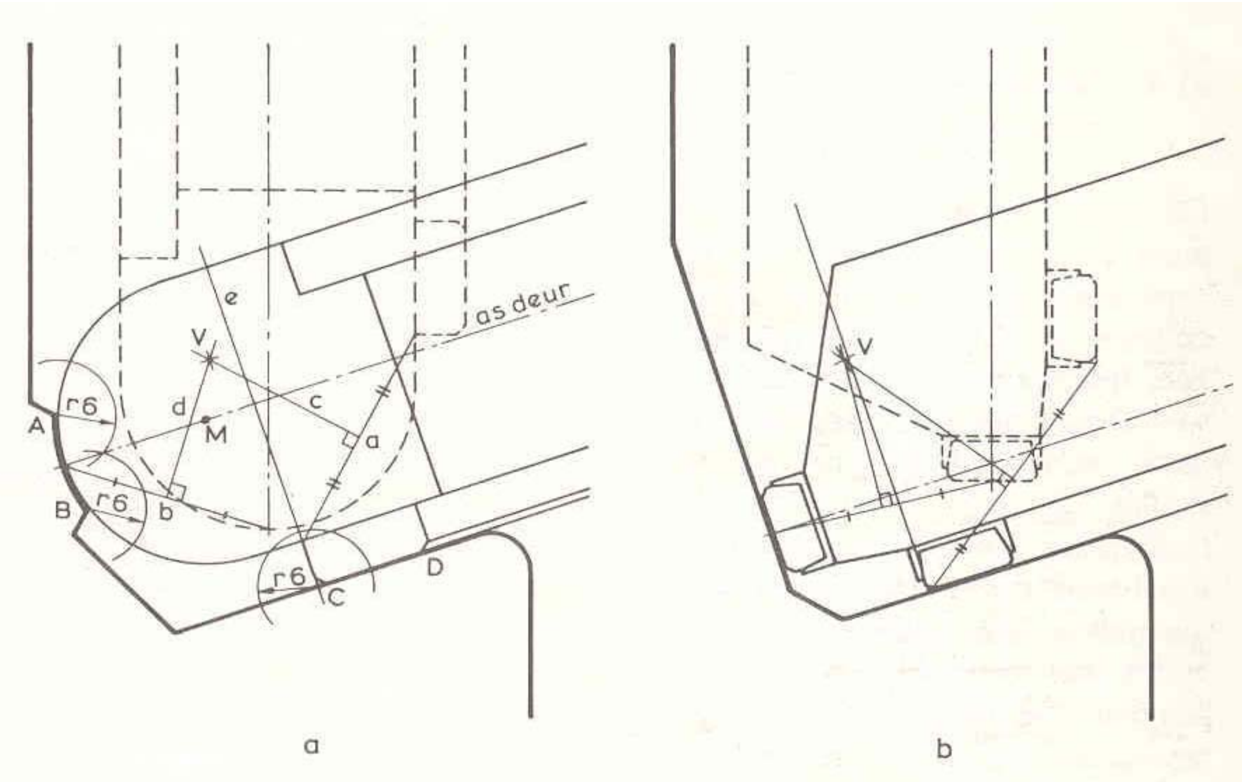

Figure 14: Principle of support location for free moving lock gates

Figure 15: Wing gates in dry condition

Figure 16: Wing gate after manufacturing by Wijma Kampen BV., the Netherlands

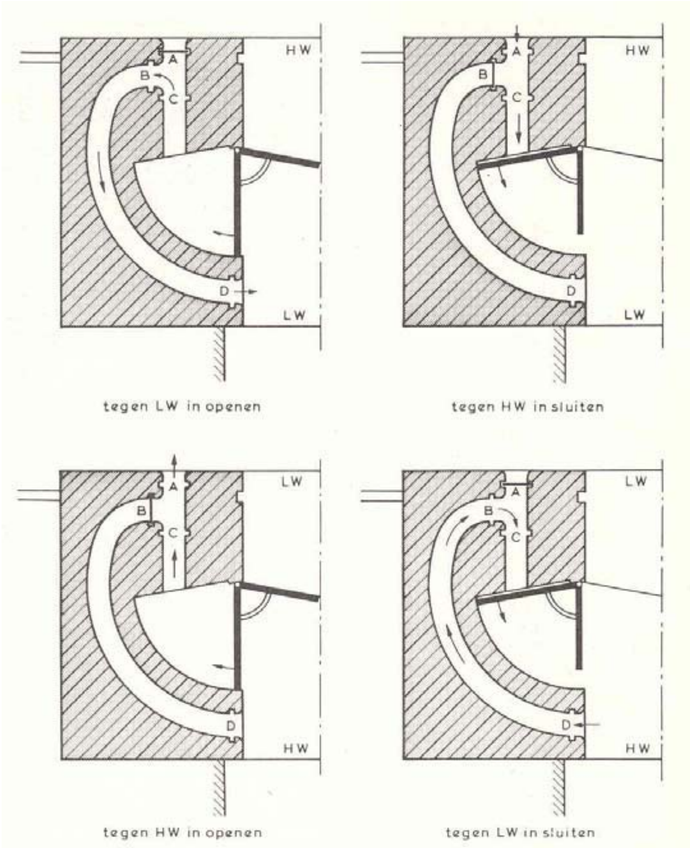

Figure 17: Principles of wing gates and water flow. HW = high water, LW = low water

Mooring and fendering structures

Moving ships need space and guidance when docking and entering near harbours and waterworks. Mooring, dolphin and fendering structures allows for this, but need to be designed for impact loads, which can be very high on the case of ships.

Figure 18: Mooring structure

These structures need to be flexible and strong at the same time. Flexibility is needed for energy dissipation for mooring ships, whereas strength is needed for possible collisions. The mechanical scheme of a pole in the ground below the water level is shown in Fig. 19. The piles are loaded in bending and the piles are founded at such depth that they are modelled with as fixed support below the ground level. In Fig. 20 and 21, a swing bridge in Delft is shown where all infrastructural works are enclosed by a timber fender structure.

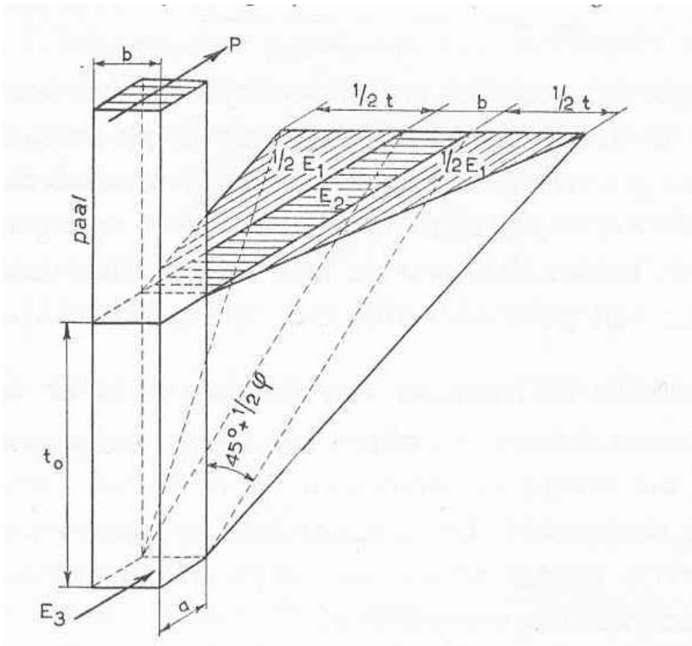

Figure 19: Transfer of point load P on top of the pile into the soil at a foundation depth of t_0.

REFERENCE

NEN 5493**:** Quality requirements for hardwoods in road construction works, hydraulic engineering works and other structural applications.

Leusen, B. van, Duikers en sluizen: Stam Technische Boeken; Culemborg, 1974.

Figure 20: Swing bridge in Delft, the Netherland, protected by timber fender structures

Figure 21: Fendering structure to protect the bridgehead