

Chapter 1: General Information on Prestressed Concrete

1.1. Introduction:

This chapter aims to present a literature review on prestressed concrete, the different tensioning methods, and the applications of this type of concrete. The two prestressing methods (pretensioning and post-tensioning) will be explained in detail, along with the various stages of execution and fabrication of prestressed concrete elements.

1.2. Definition of reinforced concrete

Reinforced concrete is a construction material in which reinforcing bars or other types of reinforcement have been incorporated to enhance one or more properties of the concrete. For many years, it has been used as an economical building material in buildings, bridges, and many other types of structures worldwide. Much of its global appeal stems from the fact that the basic constituent materials (cement, sand, aggregates, water, and reinforcing bars) are widely available, and it is possible to construct a structure using local resources, labor, and materials.

1.3. Reinforced concrete mechanics

Concrete is a composite material characterized by its significant brittleness, low tensile strength, and good compressive strength. Cracking occurs when the tensile stress in a concrete element reaches its tensile strength due to externally applied loads, temperature changes, or shrinkage. Concrete elements lacking any type of reinforcement are prone to failure, usually very suddenly once the first tensile cracks appear, as there is nothing to prevent cracks from propagating within the concrete material.

Consider the unreinforced, simply supported concrete beam shown in Fig. 1.1, which is subjected to a concentrated load P at mid-span. According to the principles of strength of materials, the maximum tensile bending stress occurs in the lower fibers of the beam section at mid-span, and the maximum compressive bending stress occurs in the upper fibers. Since concrete is stronger in compression than in tension, the beam can support the concentrated load and its own weight as long as the maximum bending stress is less than the tensile strength of the concrete in bending (Fig. 1.1a). If the bending stress is equal to or greater than the tensile strength, a crack will immediately form in the lower fiber of the beam and propagate instantaneously to the upper fiber (Fig. 1.1b).

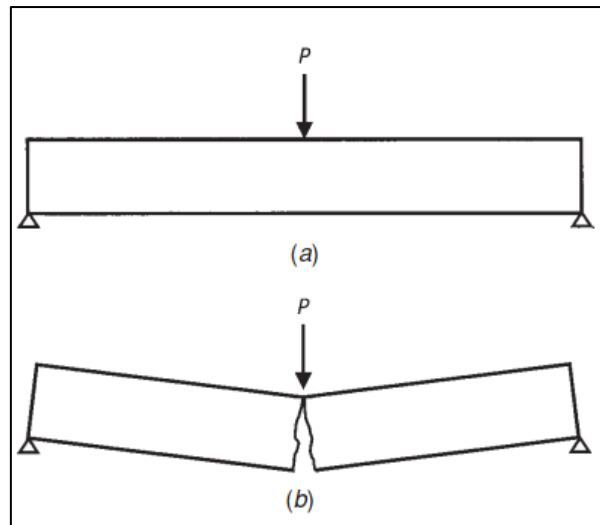


Figure 1.1 Beam simply subjected to external loading. (a) Bending stress < the tensile strength of the concrete in bending. (b) Bending stress > the tensile strength of the concrete in bending.

A different sequence of events would occur if reinforcing bars were present near the bottom of the simply supported beam. As with an unreinforced concrete beam, a crack will form in the bottom fiber of the reinforced concrete beam at mid-span when the bending stress is equal to or greater than the tensile strength of the concrete in bending. Unlike the unreinforced beam, crack propagation will be stopped by the presence of the reinforcement, which has a much higher tensile strength than the concrete. If the magnitude of the concentrated load increases, the mid-span crack will propagate stably upward, and additional cracks will form at other locations along the span where the bending stress exceeds the tensile strength of the concrete (see Fig. 1.2). Assuming the beam has sufficient shear strength, this process continues until the concrete collapses in compression or until the reinforcement fails in tension. The following chapters of this course show that it is desirable for the reinforcement to fail in tension before the concrete fails in compression.

The key takeaway from this discussion is that reinforcement bars, which have a tensile strength far greater than that of concrete, are used to take tensile stresses in a reinforced concrete element, and that reinforcement bars only become effective in resisting tension after cracks have appeared.

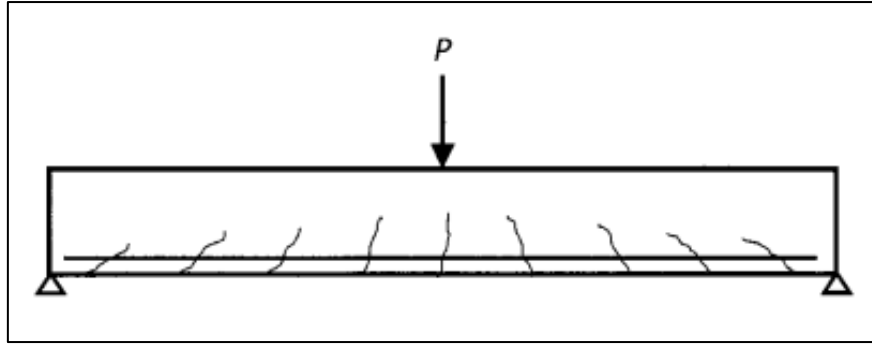


Figure 1.2 Response of a simply supported reinforced concrete beam due to an external load.

Crack widths are approximately proportional to the deformation, and therefore to the tensile stress in the reinforcement. The stresses in the steel must therefore be limited to a sufficiently low value to avoid excessively wide cracks. Similarly, significant steel deformation results from substantial curvature, which in turn is associated with significant deflection. Consequently, there is little advantage to using higher-strength steel or concrete, as the increased deformation capacity offered by higher-strength steel cannot be utilized to meet service requirements.

Prestressed concrete is a specific type of reinforced concrete. Prestressing involves applying an initial compressive load to a structure to reduce or eliminate internal tensile forces and thus control or eliminate cracking. The initial compressive load is imposed and maintained by highly tensioned steel reinforcement that acts on the concrete. When cracking is reduced or eliminated, a prestressed section is considerably stiffer than the equivalent reinforced section (usually cracked). Prestressing can also impose internal forces that are opposite in sign to the external loads and can therefore significantly reduce, or even eliminate, tensile deformations.

With improved service load behavior, the use of high-strength steel reinforcement and high-strength concrete becomes both economical and structurally efficient. As we will see later, only steel that can be tensioned with large initial elastic deformations is suitable for prestressing concrete. Therefore, the use of high-strength steel is not just an advantage for prestressed concrete; it is a necessity. Prestressing allows for lighter elements, longer spans, and an expansion of the economical application range of reinforced concrete.

1.4. Principle of prestressing

The purpose of prestressing is to eliminate (or significantly limit) tensile stresses in concrete by imposing a judiciously applied axial compressive force on the elements.

This prestress can be:

- **Partial prestressing:** permitting limited tensile stresses.
- **Total prestressing:** complete elimination of tensile stresses

1.5. Prestressing Methods

As mentioned in the previous section, prestressing is generally imparted to a concrete element by highly tensioned steel reinforcement (wire, strand, or bar) acting on the concrete. High-strength prestressing steel is most often tensioned using hydraulic jacks. The tensioning operation can take place before or after the concrete is poured, and consequently, prestressed elements are classified as pre-tensioned or post-tensioned.

1.5.1 Powering up by pre-tension

The prestressing cables are initially stretched between fixed and anchored abutments. Once the formwork is in place, concrete is poured around the high-stress steel cables and hardened. When the concrete has reached the required strength, the cables are cut or released from the abutments. As the high-stress steel attempts to contract, the concrete is compressed. The prestressing is imparted by the bond between the steel and the concrete.

Prestressed concrete elements are often prefabricated in prestressing beds long enough to accommodate several identical units simultaneously. To shorten the construction cycle, steam curing can be used to facilitate rapid strength gain in the concrete, as prestressing is carried out within 24 hours of pouring. Because the concrete is typically tensioned at such an early age, the elastic shortening of the concrete and subsequent creep deformations tend to be high. This relatively high shortening of the concrete over time results in a significant reduction in tensile stress in the bonded prestressing steel and a relatively high loss of prestress.

- **Steps for implementing prestressing by internal post-tensioning (Figure 1.3):**

Prestress is transmitted to the concrete via the cables, due to the connection between them. During the transfer of prestress, the element undergoes elastic shortening. If the cables are located eccentrically, the element is likely to bend and deform (deflection). The various stages of the prestressing operation are summarized as follows:

- A. Cable tensioning by the jacks**
- B. Pouring concrete**

C. Cable release and cutting (the compressive prestress is transmitted to the concrete by adhesion).

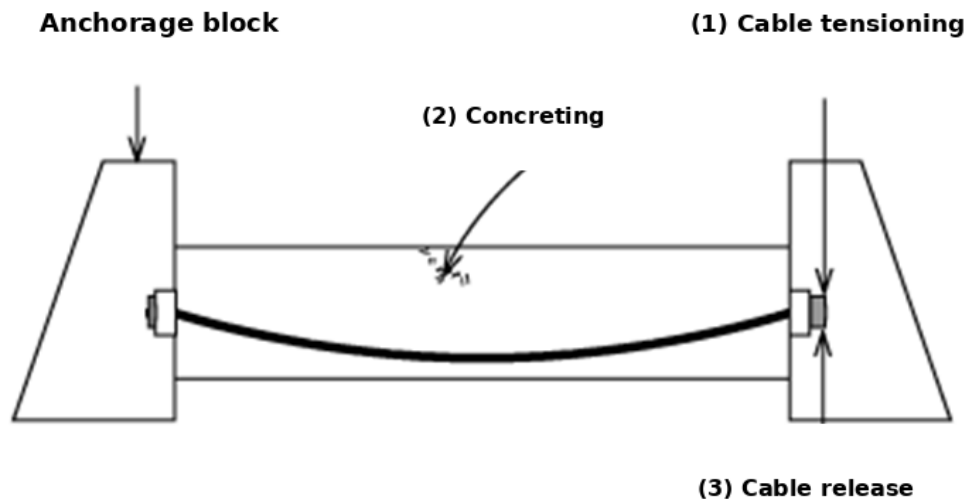
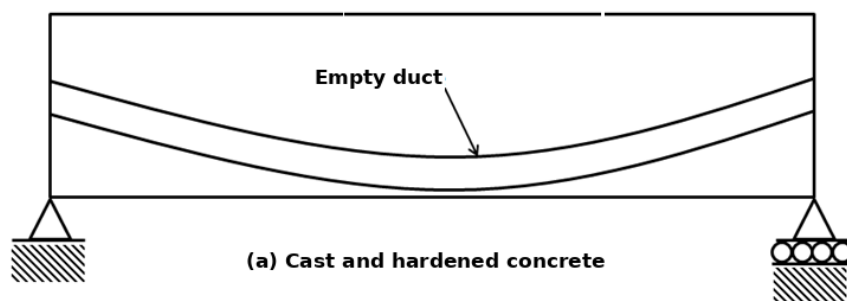


Figure 1.3. Pre-tensioning procedure

1.5.2 Powering up via a power supply:

The post-tensioning procedures for a concrete element are illustrated in Figure 1.4. Once the formwork is in place, concrete is poured around ducts that are fixed to any desired profile. Steel cables are usually in place, unstressed, in the ducts during the concrete pour, or they can be threaded through the ducts later. When the concrete has reached the required strength, the cables are tensioned. The cables can be tensioned from one end (the other end is fixed) or from both ends, as illustrated in Figure 1.4b. The concrete has undergone compressive stresses during the tensioning operation, and the prestress is maintained after the cables are anchored at the end. The post-tensioned cables also impose a transverse force on the element wherever the cable direction changes.



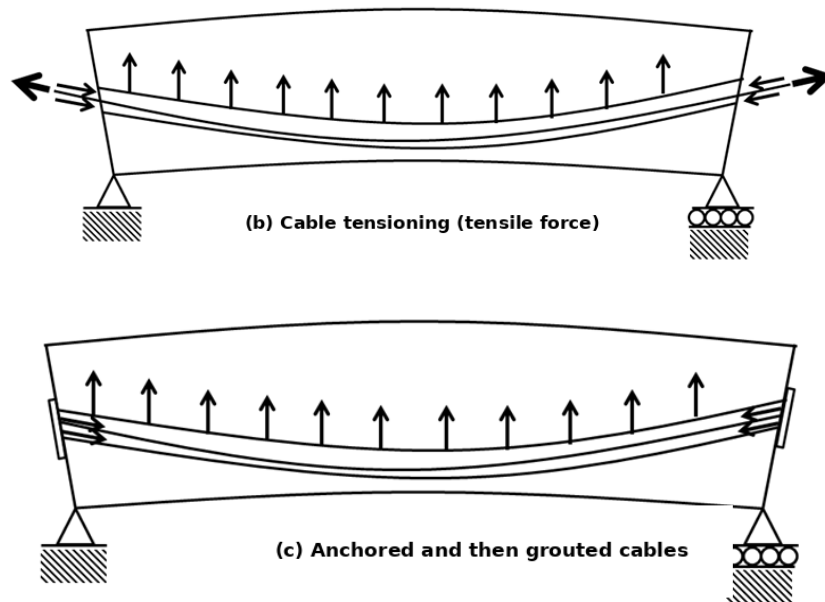


Figure 1.4. Post-tensioning procedure.

Once the cables are anchored and no further stress is required, the ducts containing the cables are often filled with cement grout or mortar under pressure. In this way, the cables are bonded to the concrete and are more effective at controlling cracking and providing ultimate strength. Bonded cables are also less likely to corrode or cause safety issues if a cable is subsequently lost or damaged. The majority of in-situ cast prestressed concrete elements are post-tensioned. Relatively lightweight and portable hydraulic jacks make on-site post-tensioning an attractive option. Post-tensioning is also used for the segmental construction of long-span bridge girders. Prestressing can also be imposed on new or existing elements using external cables or devices such as flat jacks. These systems are useful for temporary prestressing operations but can be subject to high losses over time.

- **Steps for implementing prestressing by internal post-tensioning (Figure 1.5):**

In post-tensioning systems, the conduits for the cables (or strands) are placed with the reinforcement before the concrete is poured. Furthermore, the cables are placed inside the conduits along the entire length of the element after the concrete has been poured. The conduit's role is to prevent contact between the concrete and the cables during the tensioning process.

The different stages of the post-tensioning operation can be summarized as follows.

A. Pouring the concrete.

- B. Cable installation.
- C. Installation of the anchor block and the jack.
- D. Cable tensioning.
- E. Cutting the cables.
- F. Grout injection into the ducts

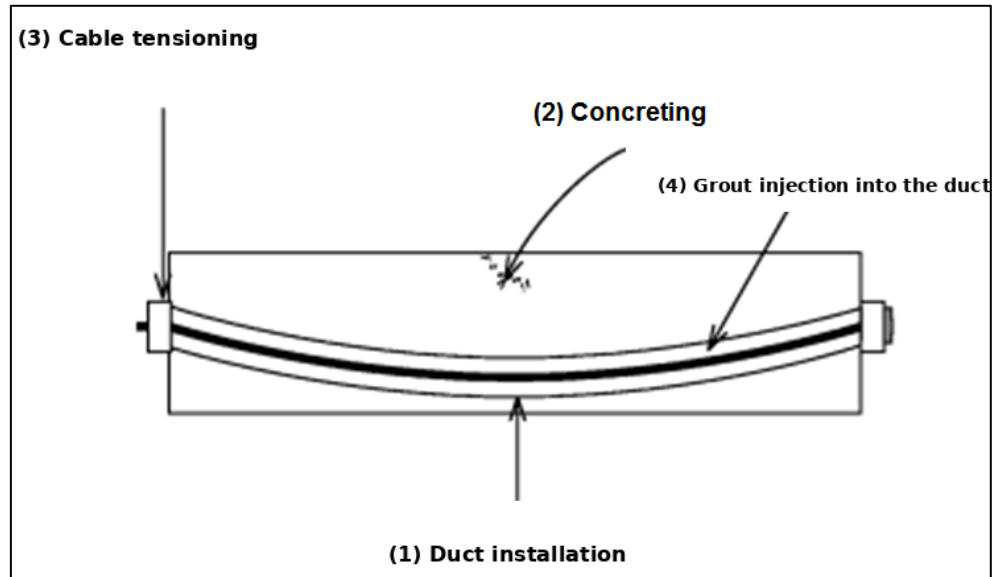


Figure 1.5. Post-tensioning energizing procedure

1.6 . Post-tensioning prestressing processes

The most widely used prestressing processes in the world are : **Freyssinet process and PAC process.**

1.6.1. Freyssinet Process:

In 1908, engineer **Eugène Freyssinet** had an experimental arch of a bridge built, spanning 50 meters and rising 2 meters. Its abutments were connected by a prestressed concrete tie rod with a working force of 250 tons. The cables consisted of 12 wires, each 5 mm in diameter, drawn from 8 mm diameter wire rod, hardened with lead quenching (Figure 1.6). Currently, other cable sizes are available, such as Ø5, Ø7, and Ø8 wires, and T13, T13S, T15, and T15S strands.

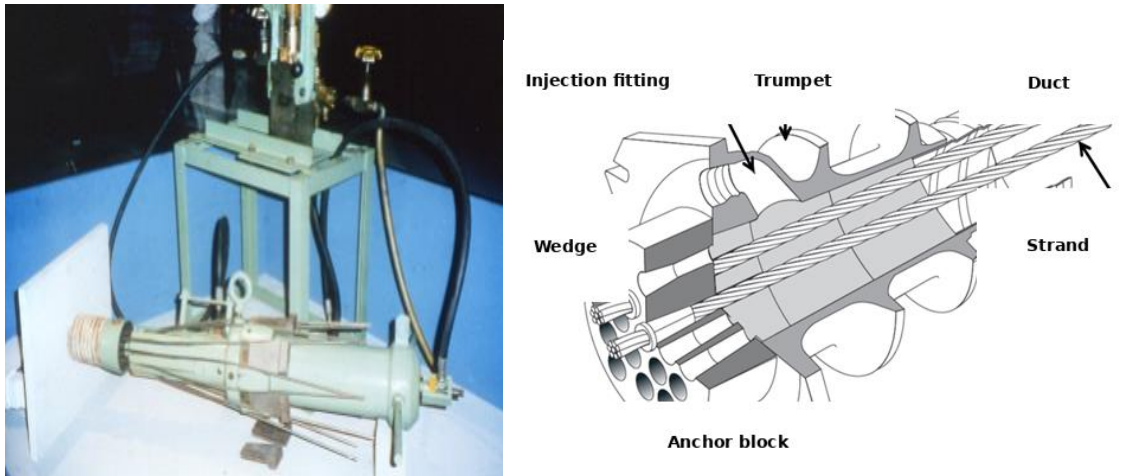


Figure 1.6. Freyssinet System

1.6.2. PAC Process:

The PAC post-tensioning prestressing process allows the concrete to be compressed by cables composed of parallel strands housed in sealed conduits (corrugated strip sheaths, smooth steel or plastic tubes).

All strands are tensioned simultaneously and anchored individually by means of three-strand keys housed in the conical holes of the anchor head.

1.7 . Comparison between the two prestressing methods

Pretension	Post-tension
The prestressing is done in the factory and is therefore suitable for prefabricated construction work.	Post-tensioning can be carried out in the factory as well as on the construction site.
In this type of concrete, the prestressing cables called strands are tensioned before pouring the concrete, then the concrete is poured enclosing the tensioned cables.	In this type of concrete, the strands are enclosed in a conduit within the mold, and then the concrete is poured. The strand tensioning process is carried out once the concrete has reached sufficient strength.
Small sections need to be built.	The size of an element is not limited; long-span bridges are built using post-tensioning.
The pre-tensioning elements are produced in a mold.	Cables are used instead of wires and jacks are used for stretching.
The concrete is prestressed with tendons before being put in place.	Prestressing is carried out once the concrete has reached sufficient strength.

Pre-tensioning is preferred when the structural element is small and easy to transport.	Post-tensioning is preferred when the structural element is heavy.
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1.8. Areas of application:

Here are the main applications of prestressed concrete.

1.8.1. Bridge construction:

Prestressed concrete has numerous applications in bridge construction. Its most common use is in prestressed concrete box girder bridges (Figure 1.7), where the concrete is prestressed in a factory before being transported to the bridge site. This type of bridge typically exhibits high strength and significant durability . Box girders are characterized by their long spans compared to other bridge types.

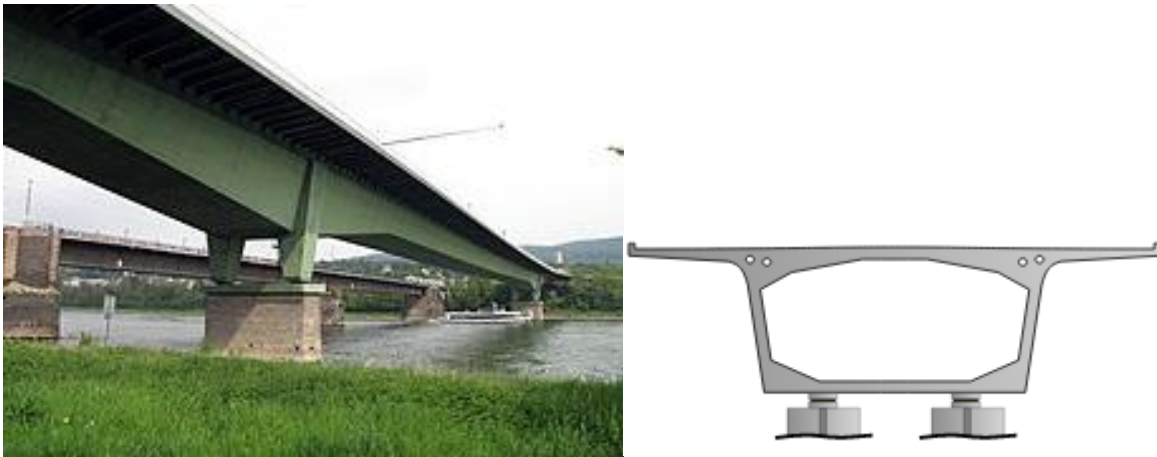


Figure 1.7. Box girder bridge

Prestressed concrete is also used in the construction of cable-stayed bridges (Figure 1.8). In this type of bridge, the precast concrete deck slab is supported by a series of cables connected to pylons. The cables are prestressed at the factory before being installed on the bridge. This type of bridge is very strong and can span long distances.

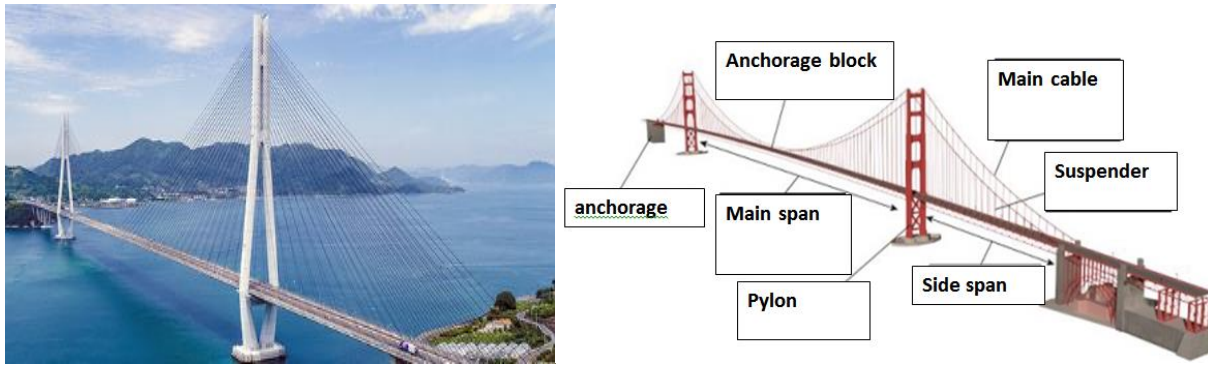


Figure 1.8. Cable-stayed bridges

1.8.2. Building construction:

Prestressed concrete is a building material commonly used in construction (Figure 1.9). This type of concrete is made by adding steel to the concrete mix, which gives it increased strength and stability. Prestressed concrete is often used for beams and columns, as well as for floor and roof slabs in prestressed concrete buildings. It is also commonly used to manufacture precast concrete products such as wall panels and stairs.



Figure 1.9. Prestressed concrete structure (Column-Beam)

1.8.3. Construction of parking structures:

Prestressed concrete is widely used in the construction of parking structures due to its advantages (Figure 1.10). These advantages include the ability to resist deflection and movement during seismic events, as well as resistance to corrosion and damage caused by wind and water. Furthermore, prestressed concrete can provide a permanent foundation for the structure, eliminating the need for regular maintenance.



Figure 1.10. Prestressed concrete parking lot floor

1.8.4. Construction of storage tanks:

Prestressed concrete is commonly used in the construction of storage tanks (Figure 1.11). The advantage of using prestressed concrete tanks is that they can be designed to withstand the internal pressure of the tank's contents. This allows for a lighter and thinner wall, which reduces the overall weight of the tank. Furthermore, prestressed concrete tanks can be designed to resist external forces, such as wind and earthquakes, that can cause a tank to fail.



Figure 1.11. Prestressed concrete reservoir

1.8.5. Railway lines:

Prestressed concrete sleepers are used in railway tracks (Figure 1.12). Prestressed concrete offers many advantages over other materials for railway track construction. It is extremely strong and durable and less susceptible to damage from weathering or other

environmental factors. Prestressed concrete is also less likely to be damaged by the weight of passing trains and can be designed to minimize the effects of vibration.



Figure 1.12. Prestressed concrete sleepers

1.8.6. Sewers:

Prestressed concrete is an ideal material for sewers because it is extremely strong and durable (Figure 1.13). It can withstand the high pressures and loads typically exerted on sewer systems. Furthermore, prestressed concrete is corrosion-resistant and does not degrade over time.



Figure 1.13. Prestressed concrete sewers

1. 8.7. Grain storage:

Prestressed concrete is a useful material for constructing grain silo facilities (Figure 1.14). Its high strength and durability make it ideal for structures that must withstand the weight and forces of stored grain. Prestressed concrete can be used to construct the walls, floors, and ceilings of prestressed concrete buildings for grain storage, as well as the support structures for grain storage tanks.



Figure 1.14. Prestressed concrete silos

1.8.8. Telephone and electrical transmission lines:

Prestressed concrete is widely used in telephone and electrical transmission lines due to its high strength and durability (Figure 1.15). The concrete is capable of withstanding the heavy loads imposed by the weight of the transmission lines and the forces generated by their movement.



Figure 1.15. Prestressed concrete electrical transmission pole

1.8.9. Concrete piles:

Prestressed concrete is often used in concrete piles because it can increase the load-bearing capacity of the piles (Figure 1.16). Prestressing the concrete allows for a more efficient transfer of loads from the concrete to the piles, resulting in a higher load-bearing capacity. Furthermore, prestressed concrete can help prevent cracking and other types of damage that can occur in concrete piles. Precast prestressed concrete centrifugal piles (PHC piles) are manufactured from high-performance prestressed concrete.



Figure 1.16. Prefabricated prestressed concrete piles