Universidad de Oviedo

Trabajo Fin de Grado

Grado en Ingeniería Mecánica - Construcción

Pretensado de Hormigón

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RESUMEN EN CASTELLANO

Título: Pretensado de hormigón prefabricado.

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Introducción:

Este trabajo fin de grado fue realizado en la Universidad de Brno de Tecnología, puesto que se trata de una universidad especializada en ingeniería civil, y la mención del grado que he realizado es "Construcción", el profesor Jiri Sedlak me propuso realizar una investigación sobre la utilización del hormigón pretensado. A continuación voy a realizar un breve resumen de en que consiste dicho trabajo.

Resumen:

- *Situacion actual del hormigón pretensado:*

El hormigón pretensado se utiliza actualmente cuando necesitamos armaduras que posean un limite elástico elevado, esto quiere decir que sea de orden superior a los 1600 N/mm^2 aproximadamente, teniendo en cuenta que el limite elástico de las armaduras de hormigón armado son más de 3 veces inferior a este valor, se observa que las propiedades mejoran considerablemente.

Ademas de esto también se usa para proporcionar a la estructurar un estado de solicitación contrario al que posteriormente va a estar sometida, es decir si en una zona de dicha estructura predecimos que se van a producir tracciones podemos generar compresiones a través del hormigón pretensado, esto también serviría para generar flechas análogamente contrarias a las que ejercerán los agentes externos en su uso cotidiano.

Este estado de solicitación previo se introducirá a través de armaduras activas ya sean de alambres, barras o incluso cordones que antes de la entrada de cargas se tesan. De este modo podremos evitar la aparición y desarrollo de fisuras.

- *Comienzos:*

El concepto de hormigón pretensado apareció en 1888 cuando P.H. Jackson desarrollo la primera patente en Estados Unidos. La tecnología de acero de la época impidió que pudiera llevar a cabo su idea y no fue hasta 1928 cuando Eugene Freyssinet definió y le dio forma a la realización de pretensado de hormigón para aumentar el limite elástico de los materiales utilizados en construcción estructural.

Desafortunadamente, como Freyssinet, un brillante diseñador estructural y constructor de puentes, carecía de las cualidades didácticas necesarias para comunicar sus ideas a otros ingenieros. Gustave Magnel escribiría el primer libro de diseño en hormigón pretensado, comunicando esta idea a diseñadores de todo el mundo. Magnel diseñó el legendario Walnut Lane Bridge en Filadelfia, que revolucionó el área de hormigón pretensado en América. Simultáneamente, Urlich Finsterwalder, constructor y diseñador alemán, estaba revolucionando los medios de construcción y los métodos para pretensado de puentes de hormigón.

Un ejemplo de esto se puede apreciar cuando Finsterwalder inventó el método de construcción de voladizo libre de puentes de hormigón pretensado, lo que permitió la construcción de puentes de estabilizado. A continuación, diseñó puentes de cinta de tensión, lo que sirvió para abarcar distancias que antes sólo puentes de suspensión de acero podrían lograr. De todos modos el gran desarrollo llegó cuando Paul Abeles y su compañero, H. Von Emperger probaron la idea del "pretensado parcial".

T.Y. Lin volvió a poner el hormigón pretensado en el centro de atención cuando organizó la Primera Conferencia Mundial del hormigón pretensado en 1957.

Poco después de esta conferencia, Lin publicó un documento técnico en el "Prestressed Concrete Institute" (PCI) en el que introdujo una nueva técnica de balanceo de carga que permitió a la mayoría de los ingenieros estructurales diseñar estrucutar de hormigón pretensado muy fácilmente.

- *Etapas del hormigón pretensado:*

Para la producción de piezas prefabricadas en hormigón se puede distinguir entre tres etapas principales, cada una de las cuales debe ser ejecutada y planificada meticulosamente ya que un error en alguna de estas etapas podría ocasionar daños muy graves tanto económicos como atentar a la seguridad de las personas. Estas estructuras suelen ser muy pesadas por lo que los daños tendrían un resultado muy grave.

<u>Primera etapa:</u> teniendo en cuenta las especificaciones de la maquinaria utilizada, lo primero que realizaremos será cortar y colocar los "torones", es decir los alambres a tensar. Estos tendrán una variacion del diámetro desde 2mm a 7mm, serán estirados en frío y tendrán una resistencia a tracción de 1700MPa aproximadamente.

<u>Segunda etapa:</u> consiste en preparar la herramienta necesaria para realizar el tensado, es decir lo que usualmente se conoce como "gato para tensar", lo primero que hay que hacer es preparar los dispositivos de protección adecuados ya que se trata de un método bastante agresivo. La colocación del gato es muy importante, se deberá situar siempre al centro y frente del alambre ya que de no hacerlo se puede escapar. También se inspeccionarán las cuñas y las cajas de tensado, si la cuña esta desgastada existe el riesgo de que el cable se escape, con el consiguiente peligro que esto conlleva. En el caso de que el equipo utilizado sea hidráulico es muy importante controlar el nivel de aceite.

Hay que tener en cuenta que aproximadamente 2 veces al año se deben comprobar el estado de los equipos de tensado con el objetivo de mejorar la eficiencia y evitar posibles accidentes laborales.

Tercera etapa: Esta última etapa consistirá en programar y ajustar la presión que debe realizarse antes de la colocación del gato. Este último paso es muy importante ya que si el valor al que ajusto es excesivo el cable de acero puede romper provocanco un peligro importantísimo, y si por el contrario el valor de la tensión es pequeño puede hacer que la estrucutura quede inservible y por lo tanto una pérdida cuantiosa de dinero. Por todo esto hay que analizar detenidamente las características del equipo, los diagramas de tensado y los valores máximos admisibles.

- *Tipos de hormigón pretensado:*

Las estructuras de hormigón pretensado se pueden tener varias clasificaciones distintas dependiendo de sus características de diseño y de su uso para las cuales fueron construidas. Dependiendo de dónde esté aplicado el pretensado este podrá ser interno o externo, aunque cabe destacar que en la mayoría de las ocasiones el pretensado se realiza internamente. Ademas de esto el pretensado puede ser circular o lineal, un ejemplo de circular podría ser estructuras circulares como depósitos o tuberías donde el acero se enrolla circularmente. En el resto de casos será lineal.

Aunque mas adelante volveremos a hacer mención sobre ello (ya que es de vital importancia) cabe destacar que se puede clasificar en pretensado y postensado, como indican las propias palabras la diferencia consiste en cuando se realiza el estiramiento de del acero, es decir si esto se realiza antes o después del endurecimiento del hormigón. Por último también la presión realizada puede ser parcial o total: cuando un miembro está diseñado de manera que bajo la carga de trabajo haya tensión de tracción, entonces se dice que el hormigón está completamente pretensado. Si se producen tensiones de tracción en el miembro bajo carga de trabajo, entonces se denomina parcialmente pretensado.

- *Materiales (Acero y Hormigón):*

En la fabricación de hormigón pretensado los aceros mas recomendables son aquellos de alta resistencia, ya que la fuerza con la que previamente se pretensó dicho acero no conviene que disminuya en un valor alto, esta fuerza depende básicamente de la relación entre el incremento inicial del acero y el decremento del hormigón. Cuanto mayor sea el límite elástico del acero, menor será la pérdida de fuerza.

El acero para pretensar también es llamado (ALE) es decir acero de alto límite elástico, esto es básicamente debido a la forma que adquiere su grafico de tensión/deformación, en el que se puede observar que la altura alcanzada por el limite de proporcionalidad en el caso del acero usado para pretensar difiere en gran medida del acero estructural que se usa comúnmente, este último tiene un característico escalón de fluencia. En estos graficos hay dos valores de gran importancia, la resistencia última y la resistencia a fluencia. El primero se define como la carga máxima que resiste el acero para el cual el fabricante nos proporciona un valor máximo, por debajo del cual nos aseguramos que el material no fallará. En cuanto a las calidades del acero se suelen definir mediante las letras “C” y “T”.

Como en el acero que usamos para el pretensado de hormigón el escalón de fluencia no está del todo claro, la resistecia a la fluencia debe ser especificada. Este valor es aquel que se da en el punto en el cual una recta que parte de la abscisa en la que la deformación es de aproxidamente 0.20%, y con una pendiente de 200.000Mpa corta con el gráfico. Si nos queremos atener al punto en el aspecto físico, sería aquel en el que se produce la descarga del elemento, se deforma permantentemente con un valor de 0.20%. Esto se toma como el valor en el que se produce una compresión o una tracción equivalente al 1% de deformación.

En este caso el fabricante del acero también nos recomienda una zona segura con un valor minimo especificado.

- *Pretensado y Postensado de hormigón:*

El hormigón pretensado se produce cuando los cables de acero están tensados antes de que el hormigón esté siendo colado. El hormigón se une a los cables a medida que solidifica, tras lo cual se libera el anclaje final de las barras de acero y las fuerzas de tensión son transferidas al hormigón como compresión por fricción estática.

El pretensado es una técnica de prefabricación común, en la que el elemento de hormigón resultante se fabrica desde la ubicación final de la estructura y se transporta hasta el sitio una vez finalizado el proceso de enfriamiento del hormigón. Requiere puntos de anclaje de extremo fuertes y estables entre los cuales se estiren los cables. Estos anclajes forman los extremos de un "lecho de colada" que puede ser mucho mayor que la longitud del elemento de hormigón que se fabrica. Esto permite que múltiples elementos se construyan de extremo a extremo en una operación de pretensado, lo que nos hace obtener beneficios significativos tanto de productividad como de economía.

La cantidad de unión (o adhesión) alcanzable entre el hormigón recién fijado y la superficie de los cables es crítica para el proceso de pretensado, ya que determina cuando los anclajes del acero se pueden liberar con seguridad. Una mayor resistencia de la unión en hormigón de edades tempranas permite una fabricación más económica, ya que acelera la producción. Para promover esto, los cables pretensados suelen estar compuestos de hilos aislados, ya que esto proporciona una mayor área de superficie para la acción de la unión que los cables de hebra agrupados.

A diferencia de los de hormigón postensado, los cables de elementos de hormigón pretensado generalmente forman líneas rectas entre los anclajes finales. En ocasiones uno o más desviadores intermedios están situados entre los extremos del cable para calibrar y poder alinear correctamente y así reducir el margen de error. Los cables rectos se usan típicamente en elementos prefabricados "lineales" tales como vigas superficiales, mientras que los cables perfilados se encuentran más comúnmente en vigas de puentes prefabricados.

En conclusión el hormigón pretensado es más comúnmente utilizado para la fabricación de vigas estructurales, placas de suelo, dinteles y tuberías de hormigón.

El hormigón postensado es una variante del hormigón pretensado donde los cables se tensan después de que la estructura de hormigón circundante haya sido fundida.

Los cables no se colocan en contacto directo con el hormigón, sino que están encapsulados dentro de un manguito protector o conducto, que se encuentra fundido en la estructura de hormigón o colocado adyacente a él. En cada extremo de cada cable hay un conjunto de anclaje firmemente fijado al hormigón circundante. Una vez que el hormigón ha sido fundido y fijado, los cables se tensionan tirando de los extremos del tendón a través de los anclajes mientras que a la vez ejercen presión contra el hormigón. Las grandes fuerzas necesarias para tensar los cables dan lugar a una compresión permanente que se aplica al hormigón una vez que el cable está "bloqueado" en el anclaje. El método de bloqueo depende de la composición del acero, siendo uno de los sistemas más comunes el anclaje "cabeza de botón" (para tendones de alambre), anclaje de cuña dividida (para tendones de hilo) y anclaje roscado (para tendones de barra).

Los sistemas de encapsulación de tendones están construidos con materiales de plástico o de acero galvanizado y se clasifican en dos tipos principales: aquellos en los que el elemento se une posteriormente al hormigón circundante mediante rejuntado interno del conducto después de la tensión; y aquellos en los que el elemento de tendón está permanentemente desprendido del hormigón circundante.

La fundición de los cables en el hormigón antes de que se produzca cualquier tensión, permite que sean fácilmente perfilados a cualquier forma deseada incluyendo la incorporación de curvatura vertical y / u horizontal. Cuando los cables son tensados, este perfilado da lugar a fuerzas de reacción que se imparten sobre el hormigón endurecido, y éstas pueden utilizarse de forma ventajosa para contrarrestar cualquier carga aplicada posteriormente a la estructura, que normalmente es en sentido opuesto a la anteriormente fijada.

- *Aplicaciones:*

El hormigón pretensado es un material de construcción muy versátil como resultado de ser una combinación casi ideal de sus dos componentes principales: acero de alta resistencia, pre-estirado para permitir que su fuerza total se pueda realizar fácilmente; Y el hormigón moderno, pre-comprimido para minimizar el agrietamiento bajo fuerzas de tracción. Su amplio rango de aplicación se refleja en su incorporación en los principales códigos de diseño que abarcan la mayoría de las áreas de ingeniería estructural y civil incluyendo edificios, puentes, cimientos, pavimentos y pilotes.

Normalmente, las estructuras de edificios deben satisfacer una amplia gama de requisitos estructurales, estéticos y económicos. Entre ellas cabe destacar: un número mínimo de paredes o columnas de apoyo; bajo espesor estructural, permitiendo espacio para servicios, o para pisos adicionales en construcción de gran altura; también en este ámbito aparecen ciclos de construcción rápidos, especialmente para edificios de varios pisos.

El pretensado del hormigón permite introducir fuerzas de "equilibrio de carga" en la estructura para contrarrestar las cargas que se aplicarán en servicio. Esto proporciona muchos beneficios a las estructuras de construcción como por ejemplo la posibilidad de desarrollar tramos más largos para la misma profundidad estructural, reducir las deflexiones lo que conlleva menor numero de soportes.

Para un tramo dado, las menores deflexiones en servicio permiten usar secciones estructurales más delgadas, que a su vez resultan en alturas más bajas del suelo o más espacio para los servicios de construcción.

La combinación de espesor estructural reducido hace que las cantidades de refuerzos convencionales disminuyan y esto da como resultado un hormigón pretensado que muestra beneficios de costo significativos en las estructuras de construcción en comparación con materiales estructurales alternativos.

Cabe destacar como construcciones más significativas en la utilización de hormigón pretensado las siguientes: “Sidney Opera House”, la torre espacio de Madrid o el aeropuerto de Zagreb.

También una aplicación muy común se da en estructuras civiles, la más importante y habitual tiene lugar en puentes, aunque también se pueden observar en presas o estructuras nucleares.

- *Ventajas y desventajas:*

Dentro de las ventajas podemos encontrar algunas especificas relacionadas con algún elemento estructural en particular, como por ejemplo en construcciones civiles, en las que se reduce el tamaño o las dimensiones de los elementos estructurales, lo que puede aumentar las holguras o reducir las alturas de los pisos. También el pretensado de hormigón permite el uso de vigas grandes (mayores de 30 m), incluso cuando soportan cargas pesadas.

Además de las ventajas generales, tales como excelente resistencia al fuego, bajos costos de mantenimiento, elegancia, alta resistencia a la corrosión, adaptabilidad, etc., el hormigón pretensado se encuentra para sostener los efectos de impacto, choque y vibraciones.

Ahorro considerable en miembros de soporte y cimentaciones, debido a que se reduce el material utilizado, además de eliminar la debilidad del hormigón en tracción, por lo que se reducen considerablemente el número de grietas.

Por último el valor de las deflexiones es notablemente menor, lo que en estructuras que van a estar sometidas a esfuerzos de flexión es un aspecto importantísimo a tener en cuenta.

También el uso de este tipo de hormigón favorece el control de calidad ya que al realizarse los trabajos en una nave industrial normalemente, los trabajadores están mas controlados para prevenir riesgos laborales y dichos trabajos se realizaran con un mayor orden que los caracteristicos de otros sistemas.

Pese a ser un sistema con grandes beneficios también hay que tener en cuenta algunos incovenientes como por ejemplo que el coste unitario de los materiales de alta resistencia que se utilizan es mayor. Aunque en contraposición a esto al ser un sistema de fabricación en serie, cuando el lote de piezas pretensadas de hormigón es lo suficientemente alto y se está dispuesto a realizar una inversión inicial, esta desventaja se compensa.

Otra desventaja es que el diseño y desarrollo de los elementos estructurales es más complejo por lo que los operarios deben ser especializados tanto para el diseño como para el montaje de estos elementos, lo que conlleva un gasto de mano de obra superior.

Las conexiones, uniones y apoyos requieren unos detalles bastante sofisticados, para facilitar esta labor se realizan planificaciones cuidadosas del proceso constructivo, por lo tanto esto conlleva un gasto superior y un margen de error muy pequeño. Los operarios trabajan soportando una presión mas importante pero como he dicho anteriormente serán operarios mas cualificados.

Por último es muy importante usar este sistema cuando verdaderamente sea necesario, ya que sino conlleva un gasto innecesario, es decir hay que realizar un análisis muy detallado de los esfuerzos que va a soportar la estructura para saber si es necesario realmente recurrir al pretensado del hormigón.

- *Conclusiones:*

Ademas del breve resumen aquí escrito, en el trabajo se pueden observar todos estos aspectos mucho más detallados, así como otras áreas en las que he investigado como las maquinas que intervienen en todo el proceso, los pasos realizados y sobre todo se puede ver gráficamente el ensamble en las armaduras, además añadir que este proyecto ha ido acompañado con la visita y el análisis en un edificio de la ciudad de Brno, al que he asistido para completar mejor el desarrollo. Durante todo este trabajo he contado con la ayuda del profesor Jiri Sedlak que ha supervisado la realización de dicho proyecto y con él que he tenido varias reuniones para el correcto desarrollo de este trabajo. A continuación comienza el proyecto final.

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

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Civil Engineering

Final proyect

PRECAST PRESTRESSED CONCRETE

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1. Introduction

1.1. Current situation

The prestressed concrete is a material of composite building appearing among different concrete types (beside concretespressed, armed, beside cement, etc.) into whom they introduce, before the bringinginto service, tensions compared to thosethat he will have to suffer.

Second product was most used in the worldafter the water, the concrete indicates aco mpound of granulats natural or artificial (road metals or sand for the first, light thegranulats for the second) agglomerated bya sociable (predominantly of somecement).

The discovery of the concrete is due tothe British engineer John Smeaton, in 1756. More than 150 years later, in1928, Eugene Freyssinet registers apatent on an improvement brought inthe concrete: it is the invention of theprestressed concrete.The prestressed concrete is a technology which aims at improving the resistance of the concrete facing very high solic itations. By creating aninitial compression allowing theconcrete to be completely constricted under solicitations, Eugene Freyssinet discovers solution to return moreresistant the concrete until then toolittle resisting in traction. A prepressureby "pretension" and a prepressure by "post tension", the first one defining atension applied to shells before thecomplete catch of the concrete, her aregenerally differentiated they back upafter the complete catch of the same concrete.

Today, the prestressed concrete isfluently used in the field of the building, in the same capacity as other concrete types. He can be used on small structures or on very big construction sites. Penetrated by bars of steel whichare put in tension, before or after its drying, it suffers a pressure, and therefore a prepressure, which augments its quality of compression. This benefit will be a true advantage during the bringing into service of accomplished work, because it is goingto oppose to the pressures of traction of other expenses, as the load of workingor the climatic load.

The prefabricated construction arose initially like an attempt of reducing costsand of increasing the rapidity of theconstruction. For it several strategieswere designed, but all of them were happening for displacing part of the constructive process to the factories, and trying processes of repetition, modularity, integration, standardization and optimization. Of course this type of proposals hadbeen realized from the beginning of theindustrial revolut ion, but it wasnecessary to wait to the global citiesreconstruction, after the second worldwar, for its widespread development.

It was necessary to construct very much, and it was necessary to make it fast and cheap. And a lot of money was not had. The process lengthened more ofthe due thing, and came up to the fabulous vegetative growth of the 60sand 70s, reinforced by the big flows of population to the cities.

The prefabricated construction spreadover the whole Europe, but with more intensity in the most industrialized countries or in the Eastern bloc, andwith major shyness in the most warm , less industrialized countries, and withmajor cultural and historical load. Likeresult, in the countries of the north of Europe a strong industry of prefabricated construction was created, while in the south of Europe, scarcely it progressed.

The big problem of the premanufacture perhaps has been that it has not had occasion to evolve appropriately. Practically it has remained in an initialstage, although the current technologyallows to realize all kinds of buildings, with the highest quality, limited price, and with any type of form. The reason ofthis stagnation has owed, fundamentally, to the social r ejection.

This social rejection has a double origin. On the one hand, after the fall of the communism they kept on constructing housings prefabricated in the Eastern bloc.

1.2. Objective

Undoubtedly, the systems prefabricated by means of elements of armed concrete are much better than the others. And on the other hand also they offer many advantages on the concrete systems “in situ”. Next its advantages are summed up and also some of its disadvantages. Disadvantages that are already beginning being solved, and that undoubtedly, there will increase the number of buildings constructed with this system, and as a result.

I want to improve the following characteristics:

- High resistance and hardiness

The prefabricated structural systems ofarmed concrete and pretensazo they canhave the same structural resistance as the conventional systems of construction. Likewise, prefabricated structural systems can be obtained, insuch a way that they are capable ofresisting any type of request, vertical, horizontal or random. On the other hand these systems have less structural distortion in horizontal elements(flagstones).

- Wide variety of architectural forms

Nowadays all kinds of pieces can bemade, with irregular forms, sizesdiverse, and capable of being assembled between if, and obtain the forms wishedby any architect, in the design of its buildings.

-Resistance to the fire

The prefabricated panels of armed concrete have in average from one until two hours of resistance to the fire, without need of any type of protection.

- Cost reduction

The construction by means ofprefabricated systems of armed andprestressed concrete can reduce anaverage of 7 % the cost of constructionof any type of building.

- Construction speed

The construction by means ofprefabricated concrete panels can be 4 times more rapid than the conventionalconstruction systems. In the same way, it can become twice more rapid than the construction by means of prefabricated steel elements.

- Thermal inertia

Due to the high weight of the constructive elements realized with armed concrete, the resultant construction has a high thermal inertia. This is very important since the energy consumption of the buildings candiminish of substantial form. In summer the buildings remain fresh throughoutthe day, since they have stored the freshair during the night. On the other hand, in winter the buildings remain warm during the night,since they have accumulate d the heat generation for thesolar radiation throughout the day.

- Acoustic isolation

Due to the high weight of the systemsprefabricated to bese of elements ofarmed and prestres sed concrete theresultant buildings have a high level ofacoustic isolation

- Sostebinility

The concrete is the building materialthat less energy has needed for its securing (approximately) 1 MJul/kg, thatis to say, three times less energy thanthe wood, 17 times less than the steel, and some 220 times less than the aluminum). For it, to construct with concrete is an energy guarantee. Never the less, the conventional structures of armed concrete are continuous, to guarantee the rigidity of the knots. For it, over come the usefullife of the building there is no any more remedy than it to knock down, with the consequent generation of residues and emission. On the other hand, the structures realized by means of prefabricated elements of concrete can be dismantled, without generating any residue. For it, the prefabricated systems based on panels of concrete assembled in situ turn into the most sustainable systems of all that exist, since they are those who need less energy, and those that less residues and emission generate.

2. History of prestressed concrete

2.1. Beginning

The ferroconcrete was discovered and controlled little by little during the second half of the XIXth century. In1906 are published "Instructions relating to the job of the ferroconcrete", which constitute the first code of French calculation for the ferroconcrete.

It is in the continuity of this period of developments and of discoveries by Eugene Freyssinet (1879/1962), graduate engineer of the national school of bridges and roadways, offers a succession of methods and of inventions which will bethe base of the prestressed concrete. He studied in 1907 and constructed in 1908, the bridge in ark of Mills (Allier) is its first experience of prepressure. The soil of foundation being bad, Freyssinet links up both veering astern of work by abootstrap, to balance the horizontal increases of the ark; rather than to work with a bootstrap in ferroconcrete, he imagines a system of shells with high elastic bord er, pretended and anchoredby a system of cotters.

After different experiments and other important developments (discovery of the concrete, bare of the effect of the vibration of the concrete inits bet works), it registers finall y a firstpatent on October 2nd, 1928; thispatent covers a technique of bet inprepressure by p retension and close fitting threads. This technology, very used today, consists in putting inte nsion of threads or steel cables on aworking bench, before making theconcrete; after catch of this one, threadsare cut, and the effort of prepressure istransmitted in the concrete by rubbing and sticking between the steel and theconcrete. Some years later, EugeneFreyssinet crosses an additional step by registered a called patent:

"System ofanchoring of cables under high pressureintended for the realisation of buildings in prestressed concrete", on August26th, 1926.

The patent describes a system implementing cables of steel put intension by jacks and blocked by asystem of cones of anchoring.The us ageof the prestressed concrete spreads then , notably thanks to EdmeCampenon; it will allow to Freyssinet to apply and to develop the invention on the construction sites of the firm Campenon Bernard. After World War II, the usage of the prestressed concrete spreads thanks to the savings of materials which he allows. In 1950, theInternational Federation of Prepressure(FIP) is created with for purpose the broad casting of knowledge and the promotion of this technology.

2.1.1. Eugène Freyssinet

Eugene Freyssinet was born on July13th, 1879 in Objat, in France. At theage of 20 years, in 1899, he enters the polytechnic School where from he willgo out graduate, before including the High School of Civil Engineering of which he will also go out with his certificate in pocket. In 1905, he will benamed engineer of bridges and put on inMills.

The beginning of ordinary career whichis however going to take a turnmattering, following its meeting withthe businessman François dealer innotions, which offers him to construct three bridges in ferroconcrete. Heinvents then a new technology, thedécintrement by jacks, which will beworth to it in 1908 to get price Academy of sciences. By constructing the bridge of Veudre, he discovers the phenomenon of fluage(post poned distortion) for the concrete. In January, 1916, on unpaid leave of hispost, he becomes the technical managerand the associate of the firm SocietyDealer in notions, Limousin and Company which will take then the name of “Society Limousin et Compagnie”, Gone about things Freyssinet.

Inventions are then going to succeedone another: on October 2nd, 1928, here gisters the patent of the prestressed concrete, with a technique of prepressure by pretension and close fitting threads. On August 26th, 1939, he registers a second patent by improving technique thanks to prepressure by post tension. In 1952 is created the international Federation of prepressure, which will allow to introduce this technique across the whole world. Some years later is created the Stup society (Society for the use of prepressure), intended to encourage the use of the inventions of Eugene Freyssinet.

The society exists under the name of “Group Freyssinet” today. EugeneFreyssinet died on June 8th, 1962 in Saint-Martin-Vésubie in France.

2.2. Development

The concrete is a material which has abig resistance facing compression butthat is fragile facing the inflexion. To remedy it, steel shells were incorporatedin the concrete, giving the ferroconcrete. In 1928, Eugene Freyssinet had the idea of preparing the concrete so that this last could face up expenses and intraction which can introduce a danger for its integrity (fissures then break).

The preparation of the concrete consistsin constricting it enough so that in everyway, compression is superior to the traction which will develop later.The prior compression of the concrete is prepressure, a vocabulary was used forthe first time by Eugene Freyssinet in 1933.

So, the prestressed concrete is aconcrete into which they introduce, before its bringing into service, tensions compared to those that he will have to suffer. The intensity of prepressure to be implemented depends of course contraction for which it will be necessary to oppose and of shortenings instantaneous and postponed of some concrete.

The principle of the prestressed concrete through the study of a beam in inflexion is introduced here. In reality, prepressure finds applications in room ssubjected to other solicitations (pure traction or pure compression).

In the calculation of the ferroconcrete, the part of the concrete which is intraction is neglected. They understand while an important part of the material"serves" only for moving away steels(boot straps) of the centre of gravity of the bent sections.On the contrary, the idea which drove to the advent of the prestressed concrete consists in putting material in a state for which it is possible to use all concrete section. They fabricate a material capable of resisting senses of solicitations under the effect of surcharges, although having pitiful performances in traction.

The concrete should not for it be tense. They then come to constrict him so that the add end of the initial pressures of compression in pressures due to surcharges drives to always constricted sections. On the face which illustrates this operation, they figure up to pressures due to the external loads, acentered compression was brought by the prior prepressure of the concrete. Effort centered driven to a constant distribution of the pressures of compression in all transverse sections of the beam. When these are figured up to the pressures of inflexion due to surcharges , a triangular distribution of resultant pressures is got.

This prepressure is created by steel tense cables, so supported by heads of anchoring leaning on the concrete. This one is then constricted. Afterwards the prepressure with the single cable, in a worry of simplification will be assimilated, while prepressure is got in general by group of cables.

The concrete of cement appeared inarchitecture thanks to mouldedconcretes and to m eretricious stones, simulation of stones of size cast inconcrete; often from some concrete of natural prompt cement. The practice of moulding started at thebeginning of the XIXth centu ry the regions where they have already known banchage of the adobe and thanks to the speed of catch of the natural prompt cement (said also Roman cement). François Cointeraux has already made moulding in Lyons and Grenoble at the end of the XVIIIth century. François Coignet was one of the most important promoter of the moulded concrete. Industrialist of Lyons, he builds his plant from Saint Denis (Paris) in 1855 inconcrete adobe which he patented.

The meretricious stone had a truesuccess in the region of Grenoble, thanks to prompt cements natural from 1840s (Cement of the Doorof France by Dumolard and Viallet, Cement from Uriol by Berthelot and Cement ofPérelle by the society Vicat; today, onlyThe Door of France and Pérelle, properties of Vicat, produce some natural prompt cement in Europe).

One everything, pipe of sewers moulded, vases, statues, alustrades, stones of angles, of claveaux, cornices, modillons, etc. This practice spread then in many big cities from Europe. Cities from the north of Italy also used the moulded cement, thanks to the prompt importing of Grenoble. Grenoble is not only the country of « white coal» but also that of « and grey»: Casamaures by 1855 and TheTower Perret 1925 testify it. In “Isere”, one built in the 19°s of many houses and especially churches with elements architectonics of moulded cement as the church of Cessieu which dates of 1850, that from Champier of 1853 or else the church Saintruno of Voiron (1857/1871), SaintBruno from Grenoble (1869 /1875) who are entirely in meretricious stones of cement prompt moulded.

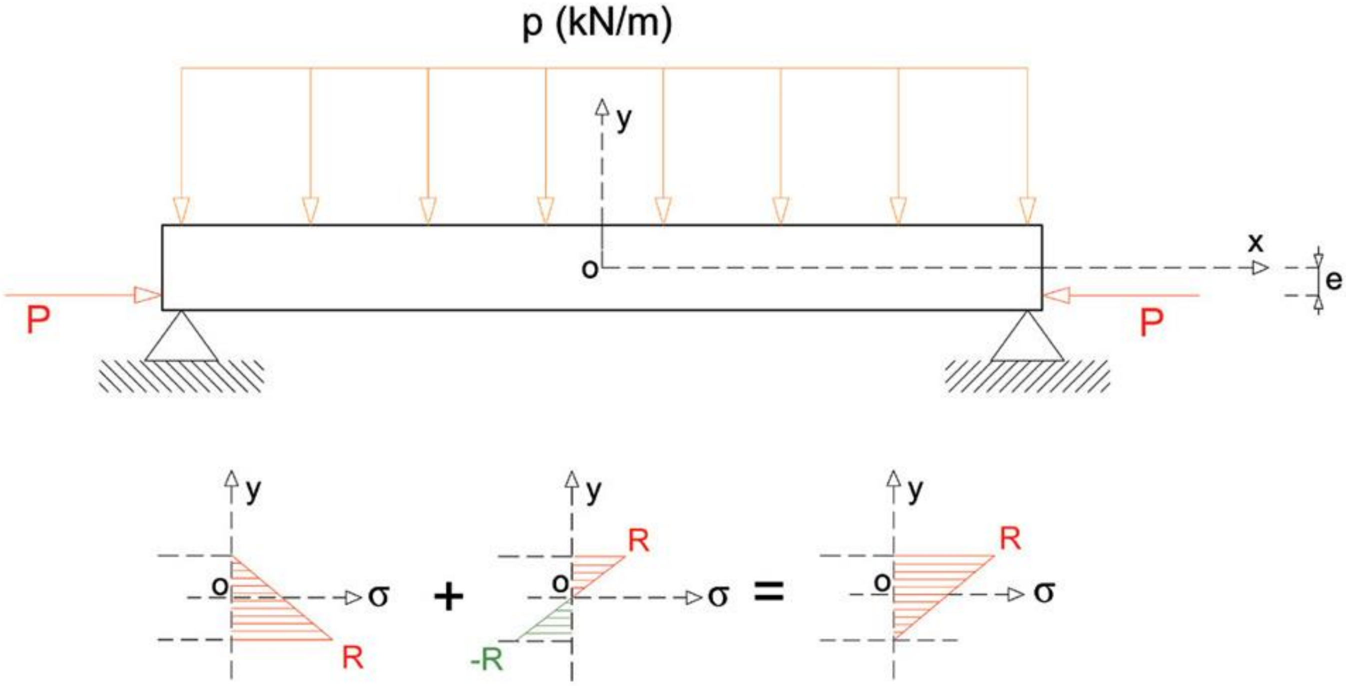
3. Stages of prestressed concrete

3.1. First Stage

For a beam subjected to the positive inflexion (arrow due to surcharges insame sense as gravity), centered prepressure, that is to say the one whopasses by the centre of gravity of sections, here to miheight, is notoptimum. Indeed, in the case of the face1 above, if R the acceptable maximumpressure in compression in the concreteis, centered prepressure is going to "use« a part of R. Let us assume that prepressure "uses « R/2. They have constricted meadow the concrete zonewhich will think constricted bysurcharges.

3.2. Second Stage

They notice in the case of centeredprepressure, that compression must belimited so that they do not exceed R/2in the zone most constricted (their napto be equal in R in the upper fibre). It istherefore judicious to excentrerprepressure so as to constrict only the material which will then be tense bysurcharges. The shape of the face is then got. The excent rement of prepressure will be such as the lower fibre will be solicited in R in the absence of surcharges. This excentrementgenerates a triangular distribution of thepressures of compression in the sectionof the beam . For an excentrement positioned inthe lower third of the beam, for arectangular beam, the pressure due toprepressure cancels each other out inthe upper fibre. They realise that thecapacity to support surcharges will thenbe doubled since these will be able tocause pressures being worth R and notR/2 as in the previous example. Consequently, in the absence ofsurcharges, the arrow of the beam willbe negative since the inflexion due to prepressure is also negative .


p (kN/m)
y
o
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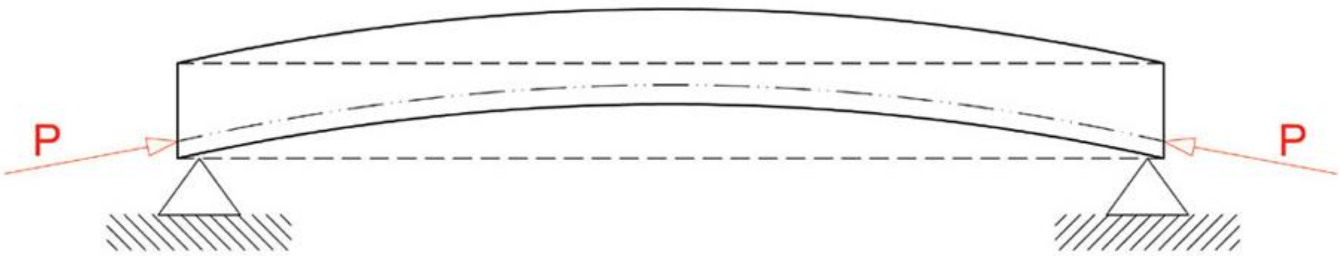
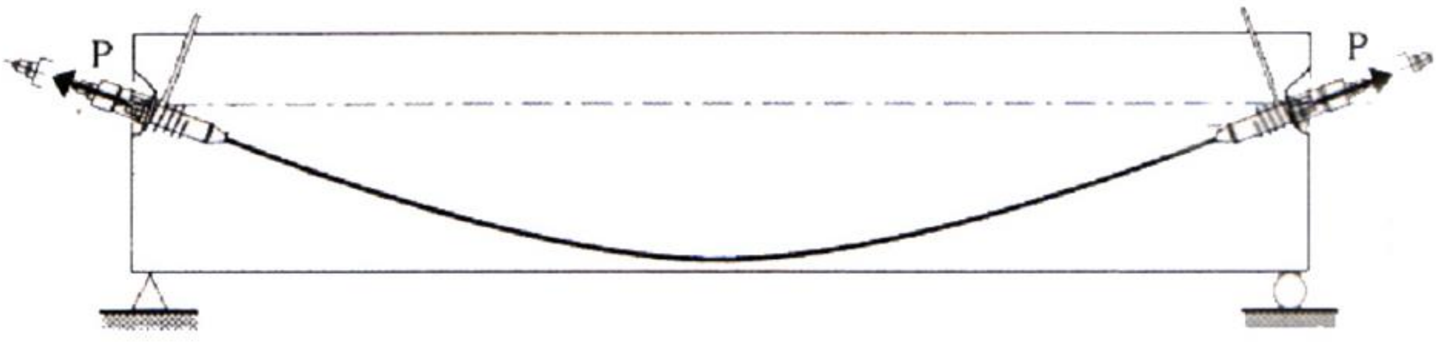

P
P

3.3. Third Stage

In fact, the clean weight of concreterooms comes to change the diagramme of pressures. An improvement madepossible by the technology of the posttension consists in making vary theeffect of prepressure along the axle ofthe beam. In the right of supports, thein flexion due to clean weight is no so thecable can be close to the centre of gravity of the section, while in carriedmi, the effect of clean weight being maximum, excentrement of the cablewill be then maximum. So, the optimumline of the cable followshomothétiquement that of thedistribution of sagging instant resultingfrom clean weight. The line of the cable thinks there therefore it is parabolic.

The principles of the prestressed concretewhich have been just illustrated regarding beams are also applied to other elementsof structure, such as posts, piles, slabs, etc.



4. Prestressed concrete types

Prestressed concrete structures can have several different classifications depending on their design characteristics and their use for which they were constructed. Depending on where the prestressing is applied, it may be internal or external, although it should be noted that in most cases the prestressing is performed internally. In addition to this the prestressing can be circular or linear, an example of circular could be circular structures like deposits or pipes where the steel rolls circularly. In all other cases it will be linear.

Although later on we will mention it again (as it is of vital importance) it is possible to emphasize that it can be classified in prestressed and postensado, as they indicate the own words the difference consists in when the stretching of the steel is realized, that is to say if this Is carried out before or after the concrete has hardened. Finally, the pressure can be partial or total: when a member is designed in such a way.

Under the working load there is tensile stress, then the concrete is said to be fully prestressed. If tensile stresses occur in the member under working load, then it is called partially prestressed.

4.1. Beams

Beams in prefabricated concrete knowdifferent applications. Beams at heightvariable s act mainly as beams of roofing, while beams in concrete at constantheight are also used as beam of floorand chief beam.

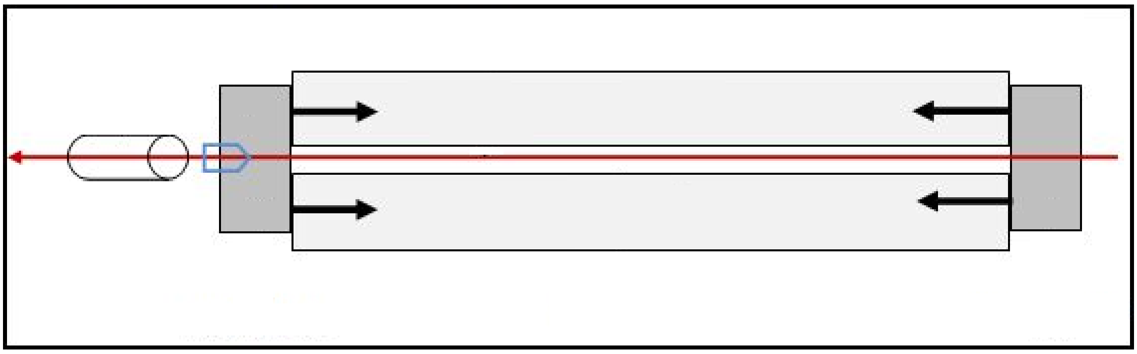
Beams in concrete at variable height areideal as beams of roofing, the incline ofbeams guara nteeing the flow of watersof rain. The variable height allows an important economy of materials. Thesebeams in concrete at variable heightconstitute since then the most economics olution to cover industrial buildings.

By working with beams in prestressedconcrete, you will make importantsavings in terms of thehours of hand of work on the construction site. Not only your plan will be faster accompli shed, but also at lesser cost.

Beams in concrete exist in two types: precompelled beams and in ferroconcrete. Beams in ferroconcrete are used as beamsof floor, beams of foundation or beams of roofing. Their section is rectangular andbeams are generally implemented of anisostatique way. They can also be endowed with shells of waiting to receive beams in asecond stage.

Beams are used inthe beams of roofing in which the slopeassures the flow of waters. The variable height allows an important economy of materials. These beams constitute then the most economic solution to coverindustrial buildings.
There are beams still – also pretended – who give a solution whenbeams in ferroconcrete do not meet adetermined load. The breakdowns of roofing in concreteare generally used when d istancebetween porticos is sizeable and thatsecondary beams are necessary tosupport the mat erial of flat roof experimental portion has aimed at the validation of behaviour in infl exion of elements in ferroconcrete. About twentybeams were cast as a result in laboratory int o objective to be subjected to statictrials in 3 points and under cyclic loads. The dimensions of beams were chosenso as to make easier the manipulation ofspecimens and according of th eavailable materials (moulds), while having proportions (L/h and b/h) nearreality.

To predict adequately the behaviour ofelements in ferroconcrete, it is above allimport ant to determine the propertiesof materials. The experimental study on materials aiming at es tablishing parametres governing the laws ofbehaviour is driven on cylindrical testtubes subje cted to pure compression forthe concrete and to pure traction for thesteel. No experimental to tal validationof the laws of behaviour on concrete testtubes was performed, they were ratherd rawn of literature.



4.2. Wires

Trials were accomplished on the concrete to determine behaviour incompression and the elastic module, according to norms ASTM C 39 and ASTM C 469 respectively,in 28 day sand the day of trials of load of the corresponding beams. It is about trials of uniaxiale compression on cylindersstandards, that is to say of 100 mm indiameter by about 200 mm high. Sincethe concrete is a heterogeneousmaterial, the variation of properties orproportion o f its constituents, as well asthe installation or the compaction leadto the variation of its final properties.

The criterion of break of the concrete incompression is established in εcult = 0.007, that is the double of distortionslinked to the maximum resistance of theconcrete in compressi on got duringtrials of module. For reasons ofconvenience and since no trial oftraction on the concrete wasaccomplished, the resistance to thetraction of the concrete is linked up withthe r esistance to the compression of theconcrete . The resistanceto traction tends therefore to aug mentproportionally in the square root ofresistance in compression. During theanalysis of the behaviour of the section, the criterion of break of the concrete intraction is established in the distortionlinked to this resistance to traction (fr cr/ E c). During the analysis of the totalbehav iour of the beam, no criterion ofbreak in traction is put down given theused approach of "Tension Stiffening".

The parametres which govern the behaviour of the bars of shells weredetermined with the aid of trials oftraction according to norm ASTM E8. This trial consists in putting bars underhigh pressure if steel and establish their medium behaviour (compelled relation - distortion) by the use of anextensomètre. The extensomètre usedin the present step is 50. 8 mm inlength, that is 2 thumbs. The length ofanchoring on both sides bars have tohave at the very least a 80 mm length tobe grabbed well by the jaws of the press. The face introduces the geometry of seven bars which were tested. The minimal diameter measured for everybar (on average by 8. 65 mm) allows theconversion of efforts into pressures since it joins the zones of weakness of the material more advantageous to procreate break.

Trials were accomplished with the aid of the press. The key parametres of behaviour are summed up, where used notation is thesame that introduced on the face that is ε represent s to it the beginning ofthe elastic set, ε sh the beginning of theportion of écrouissage (strain hardening) and the indicesucaractériseparametres in the ultimate. Three ofseven bars were rejected for various technical reasons described in. The results which follow from it are how ever introduced for the elastic part of behaviour,but they are not considered in the calculation s of averages. Some results linked to the sample are obviously moved away from average and also moved aside as a result from calculations of averages. These results are introduced in italics in the picture, while results considered incalculations are introduced in thick print.

The picture sums up stocks kept todescribe the medium behaviour of thebars of shell. It is important to note thecriterion of break for the behaviour ofthe steel, criterion established in adistortion of $\varepsilon su = 0.144$ and that the parametre, considered to be the slope at the beginning of the zone ofécrouissage, is assessed in 10000 MPA by calibration with the curves of experimental results.

Experimental assemblage used tovalidate the results of modelling wasinspired and ba sed on the assemblageused . It is about a steel rigid beam supported in three points on which are fixed two supports, the one considered fixes (blocked lateral displacements) and other of typeroll, allowing lateral displacements). Inthe fulcrums of beams, plates of steelwere glued together under beams inferroconcrete and representrespectively supports of free type. A plate is also glued together onthe top of beams, in their central fulcrum, to divide the load and to a void a bad alignment between the beam and the cell of load. All plates are flat glued together eliminating so any torsion orirregularity in the beams which would draw away concentration of pressures. Itis to note that the trial in 3 points is favoured with the intention of diminishing risks of torsion or badalignment of supports.

5. Pre-tensioning

Strands, disposed in the formwork in therequired sites, are beforehand tightened, that is to say before the coulage of theconcrete. The concrete is then made intoformworks. Once hardened and resistantenough, strands at the end of beams, and, by sticking are cut, strands solicit theconcrete in compression. This method isused in plant of prefabrication.

The shells of prepressure (threads orstrands) are tightened before concreting(in one benches of prepressure of more than100 m of length) with the aid of jacksbetween two of anchoring. The cool concrete is put inthe contact of shells. When he acquireda resistance sufficient (the rise in resistance can bespeeded), them liberatetension of threads, which are passed on in theconcrete by sticking and procreate itsbet by reaction there compression (the relaxed sons want totake back their initial length, but their sticking in the concrete prevent this shorteningand the effort which it was necessary to exercise to tighten them transmits in the concrete).

It is about a tension performed on shellsbefore the complete catch of the concrete. Shells are then unloosed.The concrete puts on then in compression by effect of sticking. This technology is generally applied in plant, with special machines, and also implemented for the prefabrication of preslabs and of girders. However, she allows to get lower stocks of prepressure in technology by posttension.

The basic principle of the functioning ofthe crossbow, illustrated by thediagramme above, is founded on the fact that the more a shell is tense, the more effort F necessary to divert herof its line of one signpost fr will be important: indeed, itis the slope of the curve of crossbow F(f) that is exploited for assess the force of tension T in testedshell.
In practice, they free themselves fromparasitic effects caused by to stiffness ininflexion, to o vervoltage introduced and in the complex geometryof the distorting of shell by an operation of calibration:

The working of the curve of crossbowindeed leans on a beam of referencecurves established in laboratory on the same type of shells.

The crossbow is constituted of a metallicframe which is put down on shell by theintermediar y of two castors, a jack of traction, of asensor of force and of asensor of displacement. The sensor of force of beach 5 - 30 kN, isadapted to the specific usage of thecrossbow: trials on t hreads, strands or cables ofprepressure (in the latter case, it isabout cables constituted by stra nds toronnées between them as in technique). The running of thesensor of displacement is of 10 mm, to measure a maximum arrowimposed on shell in the order of 3 mm.

The jack is operated by a hand pump. Both sensors are connected to a powerstation of acquis ition piloted by amicrocomputer. A lot of equipments are more over necessary to clear the concrete, to cutthe conduits up of precompelled (strap, metallic tube), and to eliminate the present coulis.

6. Post-tensioning

In post tension, behaviours intended toreceive strands are put in the formwork, according to the prestablished line. A cable is group of strands. After concreting and hardening of theconcrete up to a minimal value (to control precisely), strands areintroduced into behaviours, put together in heads of anchoring , then tightened with the aid of a jack.

After the coulage and the hardening ofthe concrete, the cables of prepressure passed in scabbards beforehand set upand anchoring, up to jacks which allowtheir bet in tension. When cables areliberated the concrete is then put incompression. The tension of cables is controlled by the measure of theirlengthening. Once the non assembled jacks and cables cut in their ends, scabbards are injected of a couliscimentaire to protect the cables ofcorrosion. Let us note that post tensioncan be internal or external in theconcrete. This last allows the change ofcables harmed or even the streng thening of structures subjected tothe upper expen ses to those initially envisaged.

Prepressure is accomplished by shells(cables or strands) put in tension when the concrete acquired a sufficientmechanical resistance (to allow him to support efforts of compression to which he isthen subjected).

There are two types of **prestressed in post tension**:

• Internal in the concrete,
• External in the concrete.

The bet in prepressure by post tension is accomplished by the succession of stages following:

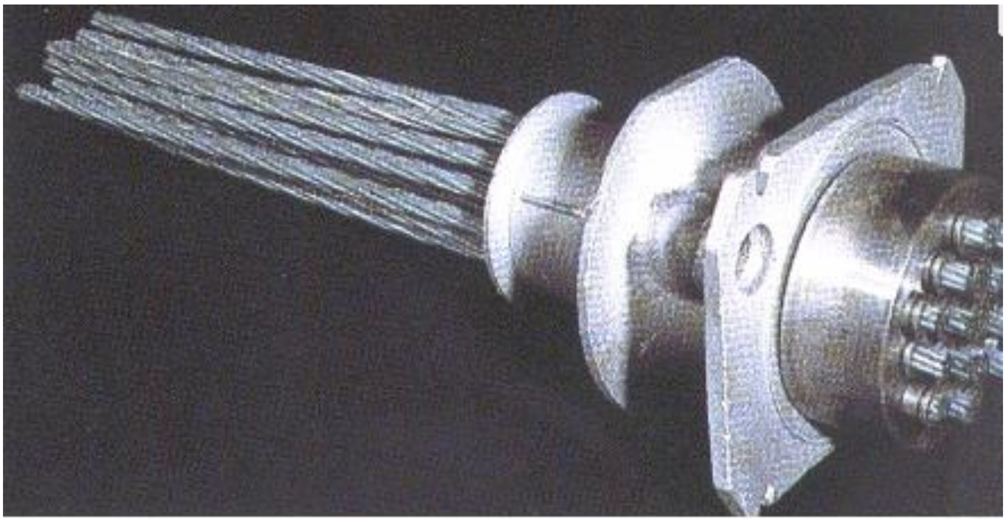
• Conduts (most used "scabbards"are)are positioned inside formwork (precompelled internal) or outside (precompelled external) front concreting.

• Shells are threaded in conduits after concreting.

• Are shells are tense in their ends byjacks and "anchored" by one systems of anchoring.

• The control of the tension of shells isperformed by measure of their lengthening (the lengthening being proportional to the tensile stress exercised over shells).

• Conducts are injected by a coulis of cement(or sometimes by waxes or of grease) to protect the shells of prepressure of corrosion.



7. Concrete prestressed

7.1. Advantages

One of the major advantages of theconcrete is his durability – it is notwithout reason that it is used to coverstreets and to fabricate bridges. Theconcrete can also be made to create almost any forms, what makes it idealfor the clients wishing forms andelements which go be yond optionsgiven with steel structures and beyondwood. Moreover, the concrete includes a high thermal mass, because he absorbsand keeps heat very well. It makes surethat buildings in concrete remain inexpenses during summer and in heat in winter.

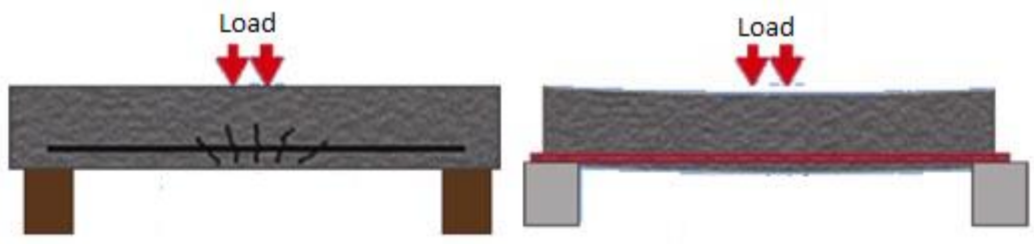
Other methods of building as the bricklaying and the blocks of constricted earth include the same advantages asthe concrete, especially the thermalmass, which becomes a convert inenergy efficiency. It is recommended touse these methods in the places where the raw materials are abundant, since itis more ecological to produce blocks onthe spot, that they are made of brick, stone or earth.

The technology of prepressure uses bigresistance in compression of theconcrete. The concrete is constrictedmeadow. So, there are no morepressures of traction which would have appeared if a load to the beam wasapplied.

Advantages there are not fissures because there isnot traction but only compression. Indeed, when a load is applied, theconcrete decompresses but does nottighten.
there is an economy of material becauseall concrete assures resistance, thesection is then smaller in comparisonwith the ferroconcrete. There istherefore less concrete and less steel.
as the section is smaller, weight issmaller. Thanks to this lightness, theranges of beams will be able to achieveup to about 50 metres. For the bridge, it was necessary to put beams precompelled given 50-metre range.

Resume of principal advantages:

- He does not break up (constricted concrete).
- He supports strong expenses andcrosses bigger ranges.
- He is thriftier in the implementation: less concrete and less steel, no wood offormwork, speed of implementation.
- He brings security and guarantee: industrial manufacture according tonorms, daily self-regulation.
- He is rigid and light: work less thick, not very fragile reduced, producedshoring up was adapted to the conditions of construction site.



7.2. Disadvantages

The concrete is naturally very strongagainst compression but not so strong intension. Consequently, the constructorsand engineers often use inferroconcrete, which contains stems of steel or of bars of shell to lend it anaugmented solidity. A type offerroconcrete is called prestressedconcrete ,because pressures led by steel wires in the material to compensate the pressure of traction.

Basic notions

Précontraints steel concrete characteristics of cables or tendons which were stretched so that they to pull in wards on the concrete and to compress it. When the concrete isdelivered under a pressure of traction asthe force of gravity on a beam inconcrete, for example, compression led by the steel tendons contributes tosupport the beam together against the pressure of traction. It resembles a lot the way you can carry a pile of books which was held horizontal by applying apressure to both ends.

Expenses

Prestressed concrete is more expensivethan the traditional building materials. Itis even more expensive than of othertypes of ferroconcrete; not only theadditional materials participate bu t thenecessary additional equipment tostretch the steel before coulage someconcrete auments the cost. With theaid of prestressed concrete in caseadditional traction is useless - in a concrete floor at ground level, forexample - would raise costs of planwithout conferring any real advantage.

Complexity

When the concrete is poured, you useforms to be sure that the concreteadopts good form, because it hardens. Prestressed concrete requires morecomplex formwork, therefore it has less a suppleness of conception than othertypes of ferroconcrete, what oftenre turns more difficult conception. Besides, the margin of error in thepreparation of prestresse d concrete is much smaller than of other moreclassical materials, therefore more vigilent and careful have to be used inthe building.

Considerations

Prefabricated metallic members oflifting in place habitually require bigcranes; these also add to the cost of thebuilding. With all these disadvantages inmind, however, it is important also tonote that the prestressed concrete hassome important advantages.His upperforce in tension allows engineers toconceive plues spans not taken care. When all is said and done, the choice between classical and precompelledferroconcrete it would be necessarybased on the type of plan and of properties that requiere.

8. Products for concrete-prestressed production

8.1. Tensioning machines

Due to the fact that the concrete resiststraction badly, the principle ofprepressure consists in subjecting it to acompression when it is not solicited in asuch way that under the effects ofservice expenses, he remains constricted.
Prepressure is implemented according to two very distinct techniques denominated respectivly:

● Precompelled by pretension: this technology is mainly used for the prefabrication of concretes elements intended for the building. For these applications, it consists in tightening ona bench of bet in tension a steel of prepressure which passes in the formwork of the element to be made and where the cool concrete is made. Once the concrete attained a sufficient resistance, got generally by concrete, the steel of prepressures unloosed and the force of prepressuretransmitted in the element by sticking.

● Precompelled by post tension: thistechnology is mainly used in civilengineering (bridges, nuclear powerstations for example) but also in thebuilding (for example slabs). It consists in tightening cables of prepressurebeforehand threaded in conduits orscabbards inserted in structure, when the concrete attained appropriateresistance, and to anchor these cables by means of devices of anchoring specific for every technique or kit of prepressure.

Steels of prepressure are steels withhigh resistance, with high content of carbon (including in general between 0,65 % and 0,85 %).

They come under form:

● Of threads of diameter 2,5 mm in 12,2mm smooth or notched (these last beingused in prepressure by pretension) the diameters of notched threadsfluently used in France being bet ween 4 and 8 mm.
● Of strands (strands are constituted products by wrapped threads some around others) from diameter 4,8 to 18 mm – in France, strands 3 threads of diameter 5,2 mm and strands 7 threads of diameter 6,85 mm in 15,7 mm are fluently used.
● Or smooth bars or in reliefs forming screw thread of diameters 15 mm in 75 mm.
These steels of prepressure are workedout according to two completely different processes of manufacture.
● The manufacture of threads and strands calls the technology of wire drawing of thread scheme with astrong reduction of section got by a series of successive passes.

The so got sons can then be notched by means of pebbles generally disposed in 120 ° (genera ting therefore 3 series off prints) or used as half product forthe manufacture of strands by me ans oftoronneuses on whom are loaded 3 or 7 spools of threads. In the case of strands threads , the central denominatedthread soul is from the slightly upperdiameter to the diameter of the peripheral threads who are wrapped inaircraft propeller around the central thread.
Most sons and strands make the objectof a treatment subsequentthermomécanique said about stabilisation which confers on them appropriate characteristics of relaxation(see below).

Strands can be delivered with a coatingof zinc or of alloy zinc and aluminium, or inform of sheathed protected strands, theproduct of protection being generally agrease or a wax and a scabbard being inpolyethylene high density.

● The manufacture of bars beginsgenerally with a rolling with heat ofbillettes to get the draught of the bar; these draughts make then the object of a thermal, mechanical treatment or a thermecanic to confer on them their final characteristics; some bars can be also taken back to form by rolling a screw thread on all or part their length. The manufacture of sons soaked and come back became obsolete.

8.2. De-tensioning machines

The main characteristics searched for steels of prepressure are:

● Geometric characteristics: nominaldiameters, nominal sections, assemble nominal line (calculated with avolumique taken mass equal to 7,81 kg/ dm3) and rectitude.
● Mechanical characteristics in traction;
◦ force in the conventional border ofelasticity in 0,1 %.
◦ maximum force.
◦ lengthening complete % in maximum force.
◦ coefficient of striction (or the insurance of a malleable break visible to the naked eye).
◦ The module of elasticity (it is conventionally equal in 205 GPA forth reads and bars and 195 GPA for strands).
● Behaviour in relaxation whichcorresponds to the loss of force noticedin constant stayed lengthening. He is characterised by trials described by norm. Specifications keep maximum loss by relaxation at 1000 h for an applied force equal to 70 %or 80 % real maximum force of the steel during a trial performed in anominal temperature of 20 °C.
● The resistance to tiredness underaxial force expressed by a curve of Wöhler (bows SN) or a diagramme oftype GoodmanSmith. The specificationsof products keep for trials of conditio nscorresponding to a point of the curve SN.

● The resistance to corrosion underpressure. This phenomenon is translatedby a cracking un der pressure due to thefragilisation by the hydrogen. Behaviourcan be assessed by a trial of corrosion atthe thiocyanate of ammonium described.
● The resistance to the tractiondiverted which is characteristicsintended to assess the behavio ur of asteel of prepressure (strands of nominaldiameter ≥ 12,5 mm used in prepressureby pos t tension) subjected to multiaxialpressures as those procreated at thelevel of a diversion or of anchoring. Sheis characterised by a trial and expresses itself in theform of a coefficient of di verted tractioncorresponding to the reduction of forcedetermined during trial.
● The aptitude for alternated foldingonly determined for threads. Shecharacterises the ductili ty of products. She is characterised by a trial.

● The sticking to the concrete which isin touch with the characteristics of form(for strands) or of surface (notched threads or bars with reliefs). She depends on the step of toronnage in thecase of strands or on the geometriccharacteristics of reliefs (height ordepth, spacing out) in the case of thenotched threads or bars with reliefs.

8.3. Tensioning servos

The stage which intervenes after theoperations of formwork consists inassuring the o perations of coulage someconcrete in these formworks. Theconcrete being a material the rhé ologieof which evolves between the exit of themixer and its introduction in banches, itis nec essary to assure the workmanshipof this process.

It requires the establishment of aprogramme of concreting which takesvarious requirements i nto account. Itincludes controls with reception allowingto assure delivery. Technology adopt edby the construction site oftencorresponds to a gravitational coulage(dumpster) associate in an internalvibration (vibrating needle).

Evolutions of materials and oftechnological techniques opened theway to other techniques as the pumping of the concrete.

This third shutter approaches theproblems of common concreting. The aspects of workmanship of the plasticityare detailed in a practical way onconstruction site. And, in the case of punctual incident, be able to determine real reasons.

The coulage of the concrete in theformwork is then treated, by way of different situations likely to be met inthe case of pumping of the concrete, then of tightening by vibration for the common concretes. The particular caseof job of auto-putting concrete is alsorecalled.

Finally, the case of concreting of deepfoundations is apart treated, consideringthe specificity of fluid concretes and notvibrate employees.

Sleepers in prestressed concrete forrailways replace for some years moreand more the use of wooden sleepers aswell in shod public networks asdeprived. They have a longer life th anthe wooden sleepers and do not requireimpregnation with some oil of tar ofcoal. All habitu al forms of sleepers canbe substituted by some prestressedconcrete.

Sleepers in prestressed concrete aregiven ready for pose, complete shell isincluded into the c rosspiece in concreteand suffered a prepressure inaccordance with norms.

8.4. Anchoring line

Make apply and bring to the workmanship of the methods of conception, of calculation and ofmanufacture of structures inprestressed concrete.
Definition of prepressure and mode ofrealisation. General principles ofprepressure.
Properties of materials. Study on the losses of prepressure. Dimensionnement isostatiques be amsand hyperstatic: choice of the transversesection; calculation of requested prepressure;line of the medium cable. Beam with mixed reaction. Instantaneous and postponed distortions.
Precompelled ferroconcrete. Ultimate limit State of inflexion, of sharpeffort and of torsion.
Conception ofstructures and use of software.

The steel for pretensioning is also called (ALE) ie steel of high elastic limit, this is basically due to the form that acquires its graph of tension / deformation, in which it can be observed that the height reached by the limit of proportionality in The case of steel used for prestressing differs greatly from the commonly used structural steel, the latter having a characteristic creep step. In these graphs there are two values of great importance, the ultimate strength and the creep resistance. The first is defined as the maximum load that resists the steel for which the manufacturer gives us a maximum value, below which we ensure that the material will not fail. As for the qualities of steel are usually defined by the letters "C" and "T".

As in the steel that we use for the prestressing of concrete the creep step is not completely clear, the resistance to creep must be specified. This value is that which occurs at the point at which a line from the abscissa in which the deformation is approximately 0.20%, and with a slope of 200,000Mpa short with the graph. If we want to keep the point in the physical aspect, it would be the one in which the discharge of the element occurs, is deformed permanently with a value of 0.20%. This is taken as the value at which a compression or a traction equivalent to 1% of deformation occurs.

9. Materials

9.1. Concrete

The concrete is a material resistant to compression but fragile in the inflexion. It is to improve the resistance to the inflexion that he was imagined to incorporate steel shells ("ferroconcrete") there. The prestressed concrete goes even farther to this domain: he allows the concrete to work only incompression. It is Eugene Freyssinet who, in 1928, had the idea of this technique which is going to revolutionise art to construct.
The objective of prepressure is to subject the concrete to permanent pressures of compression intended to compensate for force of traction which will be applied to work. Force of inflexion will come while in deduction of the force of initial prepressure. The concrete is then used at best its possibilities.

The concrete is precompelled by means of cables which are tense by jacks: the tension of cables is going to apply apressure of compression to the concrete, on which intensity depends onexpenses of inflexions that aura to sufferwork. This prepressure can be applied by pretension, that is cables are tensebefore the coulage of the concrete. She can be her also by post tension: in thatcase, cables are tense after thehardening of the concrete.

This technology allows so to accomplishworks subjected to important pressures(bridges, rese rvoirs) or structuralelements of weak thickness but ofimportant range (beams, slabs), allowsa udacious and more sophisticatedarchitectural plans than with the onlyferroconcrete. This technology applies as well to works cast in place as to prefabricated elements.

Our technicians will help you to choosethe concrete type which is the bestsuitable for your needs, and even tooptimise a recipe according todiscounted output.
Conventional concrete Fluently used for foundations, pavements, orders and floors, this concrete can contain air drawn away toimprove its resistance to cycle frosthaw and in the agents.

Useful in places difficult of access, formworks complex or including astrong density of shell of steel, this veryfluid concrete is situated all alone underthe influence of gravity. Besides assuring a staggering that can attain 750 mm, he has a sufficient cohesion tofill up almost all types of space withoutsegregation nor ressuage.

Having mainly used for castings underthe water, this very fluid concrete andwithout segregat ion (200 mmsubsidence, more or less 40 mm) contains additives which preserve itsphysical characteristics and prevent itfrom disintegrating, even in the contactof the water.
With a force of more than 50 MPA, thisconcrete is often used for concreteelements prefabric ated or precompelledrequiring a high initial resistance. It isfabricated from binary hydraulic cementor ternaire and from additives, whataugments its resistance to abrasion, itsdurability a nd its permeability in ionschlorinates. His life is thereforeextended in some climatic conditions.

Including a chemical agentantiwithdrawal conceived for slabs, thisconcrete allows to get surf acesextraordinarily glide. The reduction ofthe withdrawal, which attains 80 % after28 days, t ells cracking during theremedy of the concrete.

Projected high speed on a surfacewithout formwork, this concrete isespecially used for walls, dams andtunnels of mine. He can be fabricated bya dry or humid technique.
This concrete is up to lighter 25 % thanthe conventional concrete thanks to theuse of balls of styromousse, ofCellucrete or of zonolite. It is especiallyused as sound and thermal insulating material for roofing, as layer of levellingfor floors and roofs as well as for firewalls.
Acting as structural reinforcement, thisconcrete contains fibres divideduniformly in the mixt ure. Thesesynthetic or steel fibres reduce internalpressures and tell the cracking, augmenting the durability of theconcrete.

By adding coloured granulats orpigments to the mixture, it is possible toget a concrete of the colour of hischoice. This concrete is especially usedfor concrete slabs and decorative products.

This very thin concrete, resistance ofwhich is from 0,7 MPA, is a material ofremblayage aut ocompactant incontrolled density. No compactage istherefore necessary to get a sufficient capacity of support. Besides, its weak resistance makes an easy material thereto be excavated by means ofconventional equipment. It is used forsearches and trenches of utility.

The concrete is a mixture, in variousproportions, of granulats of cement, ofwater, min eral addenda (sometimesreplacing the cement), often of additivesand sometimes fibres. It is t he materialof building most used in the world: theythink that its annual productioncorrespon ds to about a ton per head ofour planet (in France, it is about threetimes more). This success i s due toseveral factors: the concrete is aneconomic material, fabricated fromresources most o ften local; it isresistant, lasting, insulating thermal andphonic; he participates in architecture byforms, textures, shades which he allowsto get; he is easy to implement and gets married well to the steel.

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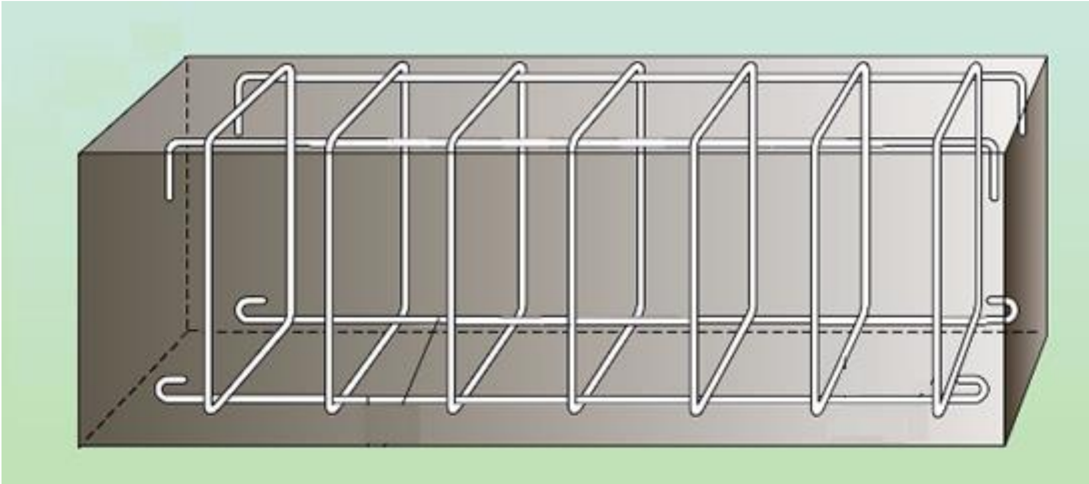
Concrete of ballast without withdrawal

This very thin concrete, resistance ofwhich is from 0,7 MPA, is a material ofremblayage autocompactant incontrolled density.No compactage is therefore necessary to get a sufficient capacity of support.Besides, its weakresistance makes an easy material there to be excavated by means of conventional equipment. It is used for searches and trenches of utility.



9.2. Steel

The steel is an alloy of iron and of carbonthe content of which of carbon is includedb etween 0,12 % in 2 %.
The iron: it is a ferrous composite metalcontaining less than 0,12 % of carbon.

Main stages of the getting of the steel, they are:
Preparation of raw materials, development of the cast iron, development of the steel.
Preparation of raw materials
After their extraction are treated sothat their reduction at the top stove ismade easier, for it or es are crushed andblended in some coke (fuel which in hightemperature does not give ash) to bethen sent at the top stove where the fuelis lighted.
Development of the cast iron
The cast iron is worked out in an ovenwith vat generally big dimensions calledblast furnace. The form of this blastfurnace is studied to give optimumconditions in chemical reactions. The blast furnace is charged with oresand with some coke and they burn. Inthe blast furnace, all iron oxides arereduced by access and deal of the iron. Through the carbon with hightemp erature, this iron carburizes andbecause of the diminution in theconsecutive melting point in its alloywith the carbon it passes in the crucible. The got products are the dairyman whoswi ms on the cast iron and the cast ironwhich contains generally 94 % of Fe. 2 - 5 % of carbon and the rest it is somesilicon, manganese and of very weakconcentration of sul phur andphosphorus. These other chemicalcomponents apart from the carbon areto eliminate in the mixer.

A concrete is defined by some criteriaand will be characterised byperformances amon g which resistance is only one of the aspects. The norm applies to allconcretes of structure, i ncluding thoseaccomplished on construction site, contrary to the norm .

Are industriallyfabricated with the advantages which itincludes (materials stocked correctly, definiteproportions (the addition of waterdepends on the content of water of granulats), systematic controls ofcomponents, regularity of thecharacteristics of the product …) They see on walked, through thenetwork of concrete plants in Job, concretes of very high resistance, regrouped underconcrete term with high performances.

In fact they recuperate a large concreterange; a classification is offeredaccording to their resistance,but not to lose sightthat word "performance" includescharacteristics various. In the course of the first decades ofhistory of ferroconcrete, shells were constituted of bars of soft steel, smooth, of circularsection of which the border of elasticity was habitually included between 215 and 235 MPA. This type ofsteel is practically more used. They use fro mnow on of steels of border of higher elasticity toreduce the sections of shells. To improvest icking shells in the concrete they create inmanufacture of asperity in projection or in hollow.

Asperity there projection tipped up in comparison withthe axle of the bar are called "bolts". Asperity in hollow is conscripts "imprinted «. These steels aresaid in High Sticking and have a borderfluently rubber band of 500MPa.

The high border of elasticity can be gotby different means:
– by playing on chemical composition, especially by augmenting the content ofcarbon. This type steel introduces disadvantages notably in the domains of the aptitude forhewing and in welding. He is left now in Europe, by drawing and orrolling with cold of bars or threads of soft steel;
– by thermal treatment (beating andautoincome) of bars or threads of soft steel. Steels often introduce in form of bars of big length or of threads in crowns. The cycles of productions used todayare in annex.
The commercial diameters of theindependent bars are (in mm):

6 8 10 12 14 16 20 25 32 40

The steel products for ferroconcrete are principally defined by norms.
Defined in these norms is indicated by letters Fe E, FE T SQUARE, TLE (steel in very high elastic border) followed by anumber pointing out the definite valueof border of elasticity expressed in MPA. Examples: Fe E 235 or Fe E 500.
More bars and threads with highsticking, benefiting from an approvalmake the object of a chip of identification.

Mechanical characteristics
The mechanical characteristics serving as a basis for the calculations of the elements of ferroconcrete are:

The noted guaranteed elastic border fe: Fe E 500 for fe = 500 MPA
According to types of steel, this bordercan be visible (soft steel, naturally hard) or fixed conventionally. Of leng thening permanent (smooth threads).
The module of elasticity of the steel is taken equal in Are = 200. 000 MPA

The diagramme pressure distortion of the steel.

As for the concrete, it is necessary to differentiate the diagramme pressure -distortion real of conventional diagramme of calculation to the who will be used for the dimensionnement of elements of ferroconcrete.

10. Aplications

Prestressed concrete is a very versatile construction material as a result of being an almost ideal combination of its two main components: high tensile steel, pre-stretched to allow its total strength to be easily realized; And modern, pre-compressed concrete to minimize cracking under tensile forces. Its wide range of application is reflected in its incorporation in the main design codes that cover most areas of structural and civil engineering including buildings, bridges, foundations, pavements and piles.

Typically, building structures must meet a wide range of structural, aesthetic and economic requirements. These include: a minimum number of supporting walls or columns; Under structural thickness, allowing space for services, or for additional floors in high-rise construction; Also in this area appear rapid construction cycles, especially for buildings of several floors.

The prestressing of the concrete makes it possible to introduce "load-balancing" forces into the structure to counteract the loads to be applied in service. This provides many benefits to building structures such as the possibility of developing longer sections for the same structural depth, reduce deflections which leads to fewer supports.

For a given section, lower deflections in service allow thinner structural sections, which in turn result in lower ground heights or more space for construction services.

The combination of reduced structural thickness causes the amounts of conventional reinforcements to decrease and this results in a prestressed concrete showing. Significant cost benefits in construction structures compared to alternative structural materials.

The most significant constructions in the use of prestressed concrete are the following: "Sidney Opera House", the space tower of Madrid or the airport of Zagreb.

Also a very common application occurs in civil structures, the most important and habitual one takes place in bridges, although also they can be observed in dams or nuclear structures.

Are privileged domains of use ofprepressure are the building and thecivil engineering structures (to seeviaduct precompelled by ToulouseBlagnac). In the domains of servicesector and industrialist, a big usage ismade of précontraints alveolar floors. These elements areacc omplished by extrusion on benchesof prepressure of more than 100 m oflength. The concrete contains very fewwater and is not adjuvanté so as to beable to support its own weight just af terthe passage of the machine withslippery formwork. Meadow tension isaccomplished by ja cks of big capacitylocated in one of the ends of the bench. Alveolar précontraints floors arest ructural optimised elements whichallow to cross ranges of more than 12 mfor expenses of of fice (see School ofarchitecture of Nantes).

Other more particular applications are toname. Freyssinet applied prepressurefor example for electrical posts(composite inflexion), or of galleries ofwater (waterproof quality).

Increases in foot of arches or of cocklescan be taken back by précontraintsbootstraps (see C NIT).

Reservoirs or silos solicited inorthoradiale traction can receive anannular prepressure which supports theconcrete in compression, just like thestrapping of the barrel.

In the field of nuclear technology, theinternal walls of the surrounding walls ofconfinement h ave to support anaccidental pressure of 0,5 MPA whilekeeping a satisfactory waterproofquali ty. Solution is brought byprepressure in 2 directions.

11. Moment of decompression in prestressed concrete

The prestressed concrete allows toaccomplish works subjected toimportant press ures, as bridges, silosand reservoirs, or structural elements ofweak thickness but important ra nge asbeams and slabs. He allows theexecution of more audacious and moresophisticated arc hitectural plans. Thistechnology applies as well to works caston the spot as to prefabricatedel ements, to surrounding walls ofnuclear reactors and to industrialbuildings.

The concrete is precompelled by meansof cables which are tense by jacks: thetension of cables is going to apply to theconcrete a pressure of compression onwhich intensity is goi ng to depend onexpenses of inflexion which work willhave to suffer. The objective ofprepres sure is to subject the concrete topermanent pressures of compressionintended to compensate for force oftraction which will be applied to work. Force of inflexion will come while indedu ction of the force of initialprepressure. This prepressure can beapplied by pre-tension, that is cables aretense before the coulage of theconcrete. She can also be applied byp ost tension. In that case, cables aretense after the hardening of theconcrete.

The shells of prepressure are steel inhigh resistance. They come under form:
of smooth or notched threads (these lastare used in prepressure by pretension) of diameter 2, 5 mm in 12,2 mm of strands which are an assemblage of several threads. There are strands in 2, 3 or 7 threads from diameter 4,8 to 18 mm. Strands 3 threads of diameter 5,2 mm and strands 7 threads of diameter 6,85 mm in 15,7 mm are fluently used.

Smooth bars or in reliefs forming a screwthread of diameter 15 mm in 75 mm. of constituted cables by several steelstrands with high resistance for theprestressed concrete. The range ofcables stretches of cables monostrandsin the cables of very big power including up to 55 strands. The most commonunits, for longitudinal prepressure, are units (composed of 12 or 13 strands) for internal prepressure and for external prepressure. A cable is defined by type, number of strands and class ofresistance.

Precompelled by post tension. After the coulage and the hardening ofthe concrete, the cables of prepressurepassed in scabbards beforehand set upand anchoring and will be routed up tojacks which will allow their bet intension. The tension of cables iscontrolled by the measure of their lengthening. When cables will be liberated, the concrete is then put incompression. Once the non assembled jacks and cables cut in their ends, scabbards will be injected of a coulis of cement (or sometimes of waxes orgrease) with the intention of protecting the cables of corrosion.

The cables of prepressure are arrangedand tightened in benches of prepressurebefore concreting. The cool concrete isput in the contact of shells. When heacquired a sufficient resistance, theyliberate the tension of the threads whichis passed on in the concrete by stickingand procreates its bet by reaction incompression. The relaxed sons want totake back their initial length but theirsticking to the concrete prevent thisshortening and the effort which it was necessary to exercise to tighten them ispassed on in the concrete. This technology is used in prefabricationand allows the production of beams, posts, precompelled slabs.

12. “Lift-slab” system

Galvanised steels are steels dressed in alayer of zinc (from 100 to 150 µm) by galvani sing with heat. They are used toreduce the risk of corrosion in structuresin ferroconcrete disp layed to thecarbonatation (when coating is veryweak) or in a very light pollution bychlorides , as in the case of chimneys, buildings located in the coast.
Galvanised shells can cause a clearing ofhydrogen during the first hours whichfollow the cou lage of the concrete,
butalso later, when the concrete hardenedand that the oxygen is lacking. That iswhy some au thors disadvisegalvanising for steels sensitive to thisphenomenon, such as the precompelled steel. According to one other , aformulation of the coulis and anadequate choice of the nuanc e of steelallow to exclude this risk almostcompletely.

The sticking between the galvanisedsteel and the concrete depends on thetype of cem ent and on the age of theconcrete .
During the days which follow thecoulage of the concrete, the stickingwith the galvanised ste el can be lessthan that got with a steel runningbecause of clearing of hydrogen tointerface an d of the dissolution of thesuperficial layer of zinc, whichpostpones the moisturising of thece ment in interface. However, aftersome weeks, the galvanised steeladheres generally well to t he concrete. Ahigher sticking can even be got thanksto the training of crystals ofhydroxyzinc ate of calcium. In practice, on not smooth bars, the sticking of thegalvanised steel is close to that someordinary steel, as much as it is linked tothe structure of surface of shells, intended t o receive a mechanicalanchoring

In the atmosphere, the protection of thegalvanised steel is assured by the layerof zinc which plays the role of sacrificial anode.
In the concrete, a layer of passivationsome zinc can form as soon as the pH is less than 13,3. This layer diminishes thespeed of dissolution of the zinc,
but alsoprevents the cathodic reactions ofreduction of the oxygen and the clearingof hydroge n. The passive film remainsstable up to stocks slightly sour pH. In aconcrete carbonaté, the s peed ofcorrosion of the galvanised steel istherefore negligible. On the contrary, ina concrete

containing chlorides, thegalvanised steel can be affected of acorrosion by injections when th e rate ofchloride exceeds cement 1 - 1,5 % massof (against 0,4 - 1 % for the ordinarysteel).

The galvanised steel can be welded, but the loss of zinc must be filled up by thelocal application of a painting in the zinc.

To avoid fissures, the thickness of zinccannot be too important. The usage ofadequate chuck s is necessary: in thecase of thick bars, chucks must bebroader, so that the layer of zincremai ns undamaged

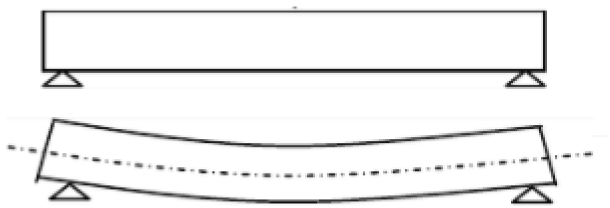
It is anyway preferable to galvanise afterfolding or after realisation of the animalboxes of shells

The contact of the steel galvanised witha steel not galvanised in the samestructure can draw away a reduction ofthe layer of zinc. It is since thennecessary to assure an electricalcomplete insulation between them. If, according to Fratesi, this riskappears only in a concrete containi ngchlorides, Broomfield recommendsnevertheless to assure a completeelectrical insulation between galvanisedsteel shells and not galvanised shells.

13. Conclusions and future lines of work

13.1. Solutions

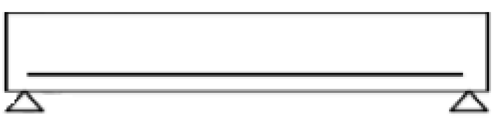
The concrete is a heterogeneousmaterial which introduces a very goodresistance to compression, on thecontrary, it has a very bad resistance totraction.
That's how a beam based on twosupports, subjected to effect of his weight clean and of a load of working , sudden of pressures of inflexion which translate by the partly upper constricted zone and by a partly lower tense zone.



The beam also suffers pressures of shearing due to sharp efforts which occur towards supports. These pressures causefissures to 45 ° which the concrete cannot take back alone. In this eventuality, two solutions are possible:

Solution N°1:

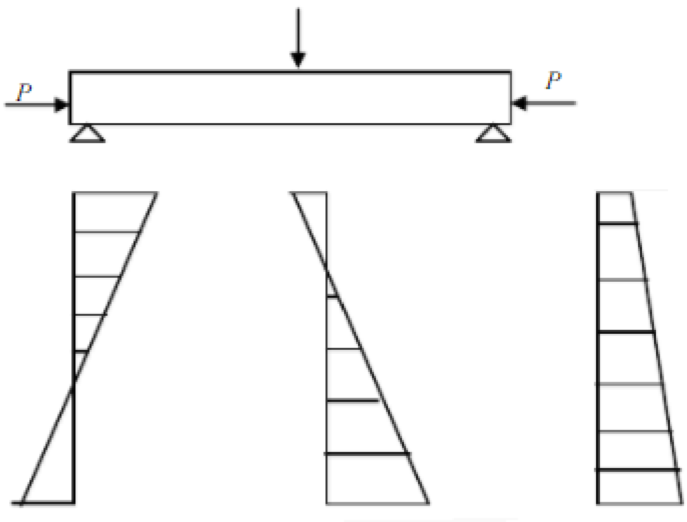
The addition of a quantity of shellscapable of taking back efforts of traction in the concrete (Principle of theferroconcrete).



Solution N°2:

The application of an axial effort ofcompression which opposes in the pressures of traction due to loads (Principle of the prestressed concrete).

Prepressure has as objective, by imposingon elements an axial effort of compression applied, to abolish (or stronglylimit) solicitations of traction in theconcrete.



The invention of the prestressed concreteis due to the franç engineer ais Eugene Freyssinet. The first practicalapplications are attracted in 1933. In theyears which follow, the exceptiona lperformances of this new concept arebrilliantly shown.

Thanks to these advantages the prestressed concrete be use in civil engineering structures and the buildings of important dimensions : it is of common use for bridges and anuse very s pread for the prefabricatedgirders of the floors of buildings.

He is found in of many other types of works, among which we will name reservoirs, piles of foundation and bootstraps ofanchoring, some maritime works, dams, surrounding walls of nuclearreactors. . .

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