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SUBWAY CONSTRUCTION AND PNEUMATIC FOUNDATIONS

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Synopsis

Methods employed in building subways and pneumatic
caisson foundations in the United States.

Engineers of The Japan Society of Civil Engineers ;

It is indeed a great honor to have been accorded the opportunity of addressing you Gentlemen. Collectively, you represent the pioneer force which is making a great industrial nation.

In this age of great populous cities, which seem to spring up as if over night, and in which dwell more people than whole nations could boast of in the past, it is the duty of the Engineer to solve all of those vital problems, that arise so as to make these huge centers livable and enable their inhabitants to function efficiently.

These problems are innumerable, it is not only those of transporting food-stuffs, and the various necessities of modern life to the city, or that of providing a suitable water system, sewerage system, highway, or waterway, but also that of providing a means for the inhabitants to move freely and speedily from point to point within the city itself. Such a system must be so planned that it taps the important centers and provides for the inevitable future growth.

The naturalist would doubtless state that the object of our lives is to propagate, that the human race may continue to exist. If we take this philosophic view, the speaker thinks that we must admit, that everything that tends to make life safe, easy and comfortable, is working in the direction desired.

Our object in life is to make a living, rather than create riches. How is

it possible to make a comfortable living for all? By increasing the production of the individual. How can this be obtained? The natural instinct of self preservation instilled in every man will result in his making a little more than a living, and this surplus or capital, will buy plant and machinery, that in many instances, will increase the production of the individual a thousand times.

This object can be attained by providing means of transportation to enable the worker to reach his workshop. Without the proper means of transportation to convey economically the worker to the place of production, it would be useless to dream of a large industrial city.

Local transportation is indeed a very human mechanism, patient and long suffering. Unfortunately, it is likewise subject to fatigue and distress, and it slows down when overloaded. The causes of this distress may be profitably examined, together with a perspective of growth and development and the great problem of planning for the future.

It is upon this matter of local transportation and that of the construction of pneumatic foundations, that I have been asked to say a few words. Either subject is monumental in scope, and therefore it will be only in a very general manner that I will be able to cover them.

Twenty five years ago, the City of New York, was in approximately the same transportation predicament as is the Tokyo of today. Its population had been increasing in leaps and bounds, and every transportation facility was taxed to its limit. Subway design and construction was still in its infancy, and many arguments were constantly brought forth in the city councils against their construction. However they were the only solution to the problem and eventually their construction was authorized.

These were so laid out as to tap the residential centers which existed at that time. The increase of population of New York has always kept one step ahead of the subway construction.

These subways necessarily passed thru the busiest business sections, under tall buildings, and under streets bordered on each side by skyscrapers. This condition necessitated expensive and elaborate shoring or underpinning. As you Gentlemen know, the buildings of lower Manhattan Island rest on a water bearing sand, so fine that it resembles quicksand. At the time of the construction of the first subways, a very small percentage of the tall buildings of lower Man-

hattan were founded on pneumatic caissons sunk to bed rock. Therefore the cost of underpinning was very great, and required the best of engineering supervision and workmanship.

Tokyo in this respect, has the most favourable condition. No matter what route is chosen, the underpinning of adjacent buildings is a very simple matter.

Underpinning of Structures Adjacent to Subway and Deep Foundations.

Perhaps the most costly item of subway and deep foundation construction, is the underpinning and protection of adjacent structures. This type of construction places all of the responsibility for the safety of adjacent structures upon the contractor himself, and therefore, he does not spare any expense in this matter and endeavours to eliminate any possibility of legal action, being brought against him due to settlement of these structures.

Underpinning work usually resolves itself, into, one of the following classes ;

(1) Light buildings.

(a) Where no water is encountered.

In this case the stealing method is employed. Inclined shores are placed on the outside of the building and small trenches are opened up under the building. These are excavated to the desired depth, and then filled with concrete. After the concrete has set, wedging stones are placed on top of same, and wedged until the load is transferred to the new footing. When one section is completed another is started, or, as in many cases, alternate sections of about five feet in length, are in operation at the same time, until the entire wall or building is underpinned.

(b) Where water is encountered.

In this case the method must be changed according to the character of the subsoil, as any loss of ground may result in serious settlement. Where there is a possibility of settlement due to loss of ground, needling or pipe piles as explained in following paragraphs are employed.

(2) Heavy Structures.

(a) Where no water is encountered, the needling method is employed, in which the wall is held by I-beams acting as cantilevers, the load being

the wall and the same method of trenches as given above pursued.

- (b) Where water is encountered.

Steel pipe piles, 12" or 15" in diameter, having a shell thickness of three eighths of an inch, are jacked down to hardpan or to the depth desired, using the wall as reaction. The soil within the pipe is blown out by compressed air and the pipe filled with concrete, after which wedging stones are placed and the load is transferred to the piles.

- (c) The most positive method, is by the use of shoring cylinders, especially, in the case where water is encountered and a heavy load is to be sustained. These cylinders are usually 36" in diameter, of cast iron, in five foot lengths. They are placed in niches cut in the wall and are jacked down using the wall as a reaction, or if that is not sufficient by weighting. Compressed air is placed on these cylinders and sandhogs remove the earth thru the airlock. This method enables one to sink to any depth within the working limits of compressed air. After excavation, the cylinders are filled with concrete and the load is transferred to them by means of wedging stones.

To emphasize the major part which the underpinning of structures plays in the construction of subways in the United States, I will quote the prices which were bid by the successful contractor for the four track subway which is now under construction in the City of Philadelphia.

Philadelphia is not noted for its high buildings, in fact until a very recent date there were few buildings over five stories in height.

The price bid for a section of this subway 8,591 feet in length, was approximately \$13,000,000 (bear in mind however when comparing with other work that this price is for a four track subway) or at the rate of \$8,000,000 per mile. Of this amount \$1,000,000 was bid for the work in connection with the underpinning of one railroad crossing, and three sewer crossings, \$100 per foot for the underpinning of buildings adjacent to the subway five stories or less in height. This \$100 however does not include any concrete necessary for the shoring, or pipe piles, it merely covers the cost of needling excavating, etc., for the underpinning.

In a contract recently awarded in New York City, where the subway paralleled the elevated railroad, and which is about $\frac{1}{2}$ mile in length, the underpinning

alone of this structure was 30% of the total contract.

As a further illustration of subway underpinning, I shall describe the underpinning of the old Bank of America building when the subway on William St. was constructed. As a matter of interest this old building is now being replaced by a new structure and the Foundation Company is at the present time constructing the new foundations, and have uncovered and removed the old underpinning.

This building was of the massive wall bearing type, which was prevalent in the 70's and 80's, before the advent of structural steel frame buildings and reinforced concrete structures. The wall and column loads rested on massive inverted brick arches, with which you Gentlemen are familiar.

Niches were cut into the wall and 15" steel pipe piles at 2'6" centers were jacked to hardpan, using the wall above as reaction. Upon these piles after they had been filled with concrete, I-beams were placed as closely as possible, embedded in concrete, and formed the girders which carried the loads. Two pieces of granite with steel plates and wedges between them transferred the load to the piles.

At the present time the City of New York has developed a comprehensive program for the extension of its transit facilities to the point of actual construction of new subways, at an estimated cost of approximately \$444,000,000. Contracts aggregating \$25,000,000 are now in force and bids are advertised for double that amount.

The unparalleled growth and expansion of the city, has overwhelmed the present municipal transportation system, before it is completed, and the population still increases and spreads. Transportation facilities are the greatest need at the present time.

The island of Manhattan which is New York City, is a rocky ridge lying North and South and having an area of 22 square miles. About 90% of the business conducted is in the lower end or South portion of the city and it is to this small area that the vast numbers of workers must be transported.

Building Foundations.

Due to the fact that the subsoil conditions of the lower part of New York, City, are very treacherous, and that rock lies at an average depth of about 75' below the surface of the ground, practically all of the recent foundations have

been placed on foundations carried down either to hardpan or to rock.

South of Canal St., and what is known as Downtown New York, the surface of the ground will not average over 15' above mean tide level. At one time this entire area of about six square miles was either part of New York Bay or swampy ground, and consequently, the first 20' or 30' encountered is filled ground. This fill overlies quicksand and hardpan, the latter usually lying next to the rock, and varying from zero to 20' in depth.

It has been found that pneumatic caissons are the best solution in carrying on deep foundation work in this section, due to the fact that they are an insurance against the loss of ground and consequent injury to the adjacent property.

There are two general types of pneumatic building foundations ;

- (1) The closed cofferdam type.
- (2) The individual pier type.

The former is the one usually employed when additional floor area is desired below street level. It also affords a deep watertight cellar where the power plant of the building can be conveniently placed and likewise makes an ideal location for bank vaults.

The construction of the foundations of the Federal Reserve Bank Building in Lower New York, probably presents the best and most difficult example of the pneumatic caisson cofferdam type of foundation.

It has the deepest cellar in New York five stories below the ground, the excavation being carried approximately 86' below street level or about 65' below ground water.

The adequate protection of adjacent structures, separated from the excavation, only by narrow streets, necessitated great care in sinking caissons so as to avoid losing any ground and required extensive timbering of cofferdams to take care of outside pressure and the surcharge of adjoining structures. Of special interest in this connection is the fact that the timbering of the cofferdam was put under an initial compression in order to avoid lateral movement of the walls which might result from the compression of the timbering.

The building itself is supported by a series of 34 large caissons forming a cofferdam along the perimeter of the lot and by 99 interior piers. The outer caissons braced across the property by the floor system act as an effective retaining structure. The caisson cofferdam was carried to solid rock in order to

make a tight seal and eliminate the possibility of any flow of water underneath the wall.

Recesses were left in the caisson to provide for the various basement floors, and on account of this it became necessary to stop the sinking of the caissons at a predetermined elevation. Below this level, excavations for the wall were carried down under air as vertical shafts to hard rock, and then filled with concrete placed under air.

An essential part of the caisson cofferdam is the seal or key between the caissons which were sunk with a space of 18" between ends. A recess was formed in the end of each caisson directly opposite to that in the adjacent caisson. After the main caissons had been sunk, the space between the caisson ends was excavated under air and filled with concrete, the recesses affording necessary clearance for airlock and shaft. Thus was provided a continuous concrete cofferdam thoroughly watertight. The cofferdam method, permitting excavation inside the walls to a great depth, not only made available at a low unit cost 2,760,000 cu. ft. of space for vault and storage purposes, but also greatly reduced the cost of constructing the 99 interior piers.

To emphasize the quantity and variety of plant required to handle a foundation contract of this magnitude, a 10,000 cu. ft. compressor plant, 16 derricks, 2 concrete plants, pipe machines, forge shop, and reinforcing equipment were all necessary parts of plant which, combined with a picked and experienced organization made it possible to have as many as 15 caissons under air at the same time.

The sinking of the first caisson was started in the latter part of August 1921, and completed Jan. 15, a period of less than five months. There were 123,000 cu. yds. of excavation, 29,500 cu. yds. of concrete, 1,000 tons of reinforcing, and 2,700,000 ft. board measure of timber used in the construction of these foundations. The cost of this work was approximately \$3,000,000.

For the foundations of the skyscrapers in the financial district of lower Manhattan Island, the company, which I and my associates represent has sunk 1,011 caissons by the pneumatic method to date.

Among the first buildings founded on pneumatic caissons in New York City are;

Manhattan Life Insurance Building

Commercial Cable Building
 Mutual Life Insurance Building
 N. Y. Stock Exchange ,,
 Broad Exchange ,,
 and The Whitehall Building

The most notable skyscrapers of New York on caisson foundations are the;

Singer Building

Woolworth Building

Bankers Trust

Equitable

Municipal

Federal Reserve Bank

and the new Telephone Building now being erected.

The above is merely a few notable examples of work of this character executed by The Foundation Company.

Bridge Foundations.

You Gentlemen are conversant with the construction of bridge caissons since their introduction in Japan, for the piers of the Eitai and Kiyosu Bridges across The Sumida River. Many of you visited the Kuramae Yard where the first caisson was built and launched successfully on the 20th of last December. The method of construction is not materially different from that employed in sinking land caissons, except that more safety precautions are adopted and the construction is much heavier.

The following contains a few of the bridges founded on caisson and built by the Foundation Company.

Clinton Bridge 4 caissons and 12 piers by cofferdams across the Mississippi River at Clinton Iowa.

Harrison River Bridge at Harrison Mills British Columbia.

8 Pneumatic caissons and 11 piers by cofferdam method.

St. Lawrence Bridge across the St. Lawrence River at Montreal Quebec.

This consisted of widening the existing piers to allow doubling tracking of a new railroad bridge, by means of pneumatic caisson, sunk in a current of about 16 miles an hour and under severe winter conditions.

Mud Lake Bridge.

In Quebec, pneumatic caissons sunk in an old lake to maximum depth possible, as no rock could be found. The caissons were belled out to give a safe unit loading on the soil.

Red River Bridges at Winnipeg Man.

Norfolk Berkly Bridge at Norfolk Va.
and many others.

Another notable use of the pneumatic process of securing safe and adequate foundations is in hydroelectric developments. When the large amount of capital invested (and most of it is first cost) is considered, the best and safest method of protecting that capital is absolutely necessary, in the consideration of its foundations.

At Hauser Lake Dam in Montana the Foundation Company was called in to sink caissons for the river section of the cofferdam thus eliminating any possibility of uplift.

The Big Eddy Dam at Turbine, Ont. and the Hales Bar Dam in Tenn. were both constructed by the Pneumatic caisson and cofferdam method.

The Michigan Northern Power Co. found its power house sliding into the Lake at Sault Ste; Marie and called in the Foundation Co. to make their plant safe, this was done by an interesting arrangement of a vertical and inclined caisson, which acted as a strut and effectively stopped any further movement.

The time allotted for this address is now up and in conclusion I wish to state that engineering ability of high degree is required to produce adequate and safe underground railways, bridges and solve difficult foundation problems.

The combination of skill, experience, and ability to direct and supervise large field forces is not easily found, and mistakes are both costly and expensive.

— The End —