THE DESIGN AND CONSTRUCTION OF THE
CHICAGO AND NORTHWESTERN
RAILWAY TRAIN SHED

BY

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THESIS

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK WILLIAM HILLMAN

ENTITLED THE DESIGN AND CONSTRUCTION OF THE CHICAGO AND NORTH-WESTERN RAILWAY TRAIN SHED

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Civil Engineer

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Recommendation concurred in:

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Committee on Final Examination
INTRODUCTION:

Dealing in futures is not confined to the board of trade speculator. In fact it is more nearly an engineer's business than that of the board of trade man. The latter deals with futures part of the time, whereas the engineer is continually planning or building something which for a basis requires a speculation in futures: namely, an investigation into what will be the conditions ten, twenty or thirty years hence.

As the power to tell what the wheat yield will be next fall is uncertain, so it is just as uncertain to foretell how many people will be living in "our town" ten years from now. Yet this condition must be approximated when the design of any engineering work is undertaken. If it is desired to build a structure that will last, its limit of efficiency must not be attained immediately, or else the building will be inadequate for service before it is really completed. The uncertainty of determining future needs is exemplified many times in all of our buildings. Continually we see buildings being torn down in order to make room for a more modern, better equipped building, and one capable of greater demands. A specific case in mind is the La Salle Street Station of the Lake Shore & Michigan Southern Railway in Chicago. About six years ago this station seemed to furnish adequate room, and, in fact, was deemed by many to be large enough for service for years to come; yet this fine station of thirteen tracks, practically in its infancy as far as stability is concerned, is, today, taxed to its limit and one wonders, how can the
number of trains be handled as they are.

This problem of handling trains in a station of antiquated, and insufficient facilities has confronted the Chicago & North Western Railway Company and to solve the difficulty it is building an entirely new terminal system in Chicago.

The present station of limited space has long since been outgrown. It is also handicapped by the fact that its approach is over a branch of the Chicago river and is subject to delays by river traffic. This latter obstacle seems to have caused the officials to select a new terminal so situated that the river need not be crossed. Therefore the site as outlined in Fig. 1 was chosen. It will be seen that all of the new work is away from the present tracks and makes an entirely new location. This was probably done so as not to elevate the large yards adjoining the present tracks, or to increase the present freight yards facilities by transferring the passenger traffic to a new location, and eliminate the danger always present where passenger traffic is through large yards. The chosen location has an advantage in that the work of construction can be carried on without the hinderance of train traffic, but has a disadvantage in that materials and supplies have to be hauled considerable distances because of the lack of supply tracks. The Chicago & North Western Railway Company created the office of Terminal Engineer, whose duty it is to handle all of the engineering of the project. The railway's regular Land Department cares for the purchasing of the land, and its Law Department, the legal work necessary in condemnation suits and drawing of contracts.

The preliminary survey resulted in deciding upon the layout as heretofore mentioned and shown in Fig. 1. This consists of two four-track approaches (one from the north and one from the west)
merging into six tracks called the Terminal Section (from the junction of the approaches to Lake Street) ending in a sixteen-track train shed, three hundred and twenty feet wide, and station; all of the work being elevated and not a street depressed. These divisions were made for convenience in letting out the work and for ease in accounting. That portion between Lake Street and the station is known as the Train Shed and Train Shed Track Section, and will be the subject of this thesis.

ORGANIZATION:

As mentioned above the engineering work is under the direction of the Terminal Engineer. The work is naturally divided into the office and field work. The former is under the direction of a Chief draughtsman and consists of making all the designs and plans for the work. The field work is under an Assistant Terminal Engineer, who has four Assistant Engineers under him, a timekeeper who checks the pay rolls, a material clerk who sees that material is furnished and a trainmaster to care for the train service necessary to place material at the most advantageous points of the old yards. The Assistant Engineers are directly in charge of sections of the work and have parties under them, consisting of an instrumentman, a rodman, one or two chainmen, pile recorders and masonry and steel inspectors.

The site chosen for the train shed was covered with very substantial buildings. The uncertainty of their foundations and the crowded conditions, made it necessary to have the work of excavation, pile driving and concreting done on a percentage basis, the contractor receiving for his remuneration a per cent. of the pay roll. The contractor also receives a certain per cent. of the pay roll in addition for the risk of insuring the company against all accident suits.
and another per cent. for depreciation of equipment. The Railway Company furnishes all material for the work, and certain parts of equipment which are very destructible, such as ropes for the pile drivers. A general superintendent is in charge of the contractor's interests and under him are all the foremen, timekeepers, material clerks, watchmen, storekeepers, hoisting engineers and blacksmiths. There are foremen of excavation, concreting, pile driving, carpenters, electricians and teamsters. The latter made necessary by the material having to be hauled some distance and carting away of excavation. Each foreman hires his own men, the timekeeper giving the men numbers and entering their names after the number given, the men thereafter, as is customary on large contracts, being designated by number. It may be suggested here that a very good way to keep time is to give each class of workmen certain ranges of numbers. For instance, all laborers have numbers, 1 to 1000, carpenters 1001 to 1100, bricklayers 1101 to 1200 and so on. This keeps the different rates together and facilitates the making of the pay roll.

**LAYING OUT:**

In order that all the space on the street level and under the tracks might be utilized, it was planned to carry the tracks on steel construction. By referring to fig. 2, the general arrangement of the tracks and columns supporting same, and of the street level floor can be seen. Between the station and Washington Street is a carriage driveway to a station building entrance, a baggage room and driveway to the latter. In Washington Street there is the approach to the old street car tunnel under the river, which has to be remodeled. Between Washington Street and Randolph Street are cab and automobile stands, a mail room, ticket office, emigrants' waiting
room and a suburban concourse for entrance to the suburban trains. Between Randolph and Lake Streets are rooms for express and mail, lamps, baggage and other equipment. All of these are on the street level and under the tracks. This same figure shows the track arrangement and column spacing. It will be seen that there are two sets of transverse column spacing, one regular 18'-0" and the other an alternating spacing of 26'-9" and 12'-6" or 12'-0". The latter is used in the shed and where the tracks are straight enough to enable them to be carried on top of the longitudinal stringers and without ballast. The 18'-0" spacing is used where the tracks become complicated and necessitate ballast floor construction, and is outside of the shed which is shown by hatchure, (Fig. 2).

There being a continuous stretch of steel for nearly three blocks it was necessary to make a very accurate survey of the streets. This was done by running a base line along Clinton Street. The intersection of this line with all the street lines were determined and the intersection angles very carefully read by repetition; eight successive readings being taken. The measurements were made directly on the sidewalks, no plumbing up at ends of chain being done, and corrected for slope and temperature, the tape also being stretched to a pull of ten pounds. This survey is shown in figure 3. Later all of this survey was referred to co-ordinate axes assumed north and south and east and west. The work of the entire project was likewise referred to these axes which were so placed that everything lies in the first quadrant. This makes it possible to easily find the relation of points with the aid of analytical geometry.

25'-6" was settled upon as being the most economical length
for the longitudinal spans, the 12'-0" center is the minimum spacing for centers of passenger tracks, the 12'-6" spacing is used in four instances to give room for belt conveyors between the tracks for conveying mail from the mail coaches to the incoming mail room, 6'-0" is the standard spacing center to center of stringers so this determined the 18'-0" spacing, it being a multiple of 6 and making it possible to have some uniformity in the transverse floor beams. The original alignment of the streets had to be maintained, and as none are at right angles to each other, odd and diverging bays or spans had to be placed adjoining each street and skewed bents put in.

With the above mentioned spacing determined, the layout of the steel work for the office use was simple and resulted as shown in Fig. 2. Then the steel work was designed and the calculations of loads on columns determined so that the foundations could be designed. The outline of this thesis, however, will be according to the method of constructing the work. This is as follows: laying out the work (part of which has been already described), excavation, pile driving, concreting and steel work.

The first thing to do in laying out any engineering work in the field is to establish base lines. These must be easily accessible, located if possible so that they will not be destroyed during construction, and bear some simple relation to the lines of the work, so that the latter can be easily and quickly established as needed, it being impossible to preserve actual points in their actual places.

With this in mind the problem of establishing base lines was the first one approached. It was decided to have two lines parallel to the longitudinal building lines, one on each side of the building and on the sidewalk across the street, marking the points
on the lines by crosses cut in the walk.

As the base line of the original survey was on the west side it was simpler to locate the west base line. Therefore calculations were made to determine the distances on the north lines of the transverse streets from the original base line, of a line 70 ft. from and parallel to the building line. Four points were located, one at each street, then checked for a straight line by setting up a transit at one end, sighting through to the other end and checking the intermediate points for coincidence, and found to check very closely. The traffic on the streets made it difficult to see three blocks so a Sunday morning was chosen for the final checking. Having established the west base line, the east one was located by right angling from the west base line at the four streets and measuring 460 feet. Some difficulty arose in getting these points to check for coincidence, however, to make a difference of .01 ft. in length in a distance of 300 feet the divergence from parallel would have to be 2-1/2" and as the error was less than 2" in about 1000 feet, the line was not corrected. However, the east line was used to establish only the transverse bent lines, and all the longitudinal lines were located from the west line. By referring to Fig. 2, we see that the first transverse bent each side of the streets makes a right angle with the building. This bent was located by measuring from the street line and establishing its intersection with the two longitudinal base lines. Then the angle was checked from the west base line, and if necessary, the points were moved so as to make the angle equal 90 degrees. With these bents located it was an easy matter to fill in the blocks, or rather to establish all the intersections of the other transverse bents by measuring along the base lines.
To care for the expansion of the steel, expansion joints are placed in the center of Washington Street and Randolph Street and on the south side of Lake Street. Therefore the work was laid out by measuring each way from the north line of Washington Street, throwing any error that might arise into the Randolph Street expansion joint. Then starting again at the north line of Randolph Street and putting any error in the north block into the Lake Street expansion joint.

Having established all of the intersections of the transverse bents with the two base lines, the longitudinal interior lines were located. This was done by running lines down each street at right angles to the west base line and establishing a transverse base line in Washington, Randolph and Lake Streets.

With this system of base lines any pier center can be quickly located by intersecting the two lines upon which the pier is located. For convenience in describing locations the transverse bents are numbered from 1 to 44. In the 18'-0" spacing the longitudinal lines are lettered from A to S, the west building line being A. In the irregular longitudinal spacing the east building line is A. This makes it possible to locate any pier in records, as for instance, pier 36 A is at the intersection of bent 36 and line A.

As all of the cross streets are being remodeled it is necessary to watch the transverse base lines and transfer the reference points before they are lost. Therefore as soon as a pier is finished the base line point is transferred to it, this will last until the steel work is placed.

The City ordinance fixes elevations and grades, and naturally, with reference to the City's datum. It is necessary, therefore to establish bench marks referred to the same datum. To do this
levels were run from two of the City's precise level standard bench marks, and new bench marks established on every street corner adja-
cent to the work, and at points not likely to be disturbed. These
were carefully checked before being accepted. Sometimes it is
convenient to have benches nearer to the work, therefore temporary
bench marks are set, and frequently checked, because being on the
work, they are likely to be disturbed. Great foresight on the part
of the Terminal Engineer was shown by his ordering levels taken on
all buildings near the work for evidence in case of law suits for
damages to buildings on account of settlement caused by the distur-
ance of pile driving. Because of the same possibility of disturb-
ance, the bench marks will be checked as opportunity is afforded.
The steel work will be set some time next summer and it is the in-
tention to check up very carefully all the base lines before any
points for steel work are given.

EXCAVATION:

So far as methods of excavation are concerned, there were no
unique methods used on this work. In fact, it was almost out of
the question to try and use anything besides pick and shovel because
of the crowded condition and also because there is hardly any con-
tinuous digging, the digging being in spots. As mentioned before,
the site was covered with buildings. These were all sold to wreck-
ing companies, the highest bidder getting the building. He wreck-
ed the building down to the street or basement level and removed all
the material. This left the foundations, engine beds, etc. in the
ground, and much of these, coming in the way of the new piers, had
to be taken out. To avoid taking out any more dirt than was
necessary, the excavation was all staked out. Then the holes were dug out deep enough to insure that all obstacles to pile driving were removed. Sometimes when the drivers were crowding the diggers, the piles were located and soundings made with a steel bar. If there was nothing encountered, the piles were driven without digging and followed to the required depth. In very few cases, however, was this possible, nearly always old foundations had to be moved, making the excavation very hard and tedious. As the pile drivers can work in weather that excavators cannot, three shifts of laborers were used, each shift working eight hours. So that the shifts would not interfere, or rather so that one shift could quit as the other started the men worked eight hours straight, stopping ten or fifteen minutes for lunch, the time paid by the contractor. These extra two shifts were continued until the excavation was far enough ahead of the drivers to warrant laying the diggers off.

The digging afforded many surprises. Old foundations appeared where least expected. Some of these were of I-beam grillage surrounded with and resting on concrete and carrying stone walls, varying in thickness from 18" rubble walls to large stone walls four and five feet thick. Fig. 4 shows a solid stone wall nearly six feet thick extending five or six feet below the basement floor. Such foundations made it necessary to dig three, four and five feet deeper than planned because of having to get out all of the old foundations. The necessity of investigating such places as these, namely, locations of old buildings, was brought forcibly to the writer's notice on two occasions. One was when it became necessary to get ready quickly for a driver. The place was covered with a cement floor with the foundations of the old building apparently
well in view. The new piers were laid out so as to know where
to tear up the floor and also to make sure that there was nothing
under the floor which would interfere with the driving of the piles.
The floor was torn up and still everything seemed clear, as the
cinder sub-foundation covered the entire space opened, so the dig-
gers were moved to where there was known to be foundations in the
way. The piles were being staked out in the former place, but
some of the stakes could not be driven more than a few inches. In-
estigation revealed stone piers, three 12" courses deep, 3 feet
square on top and 5 feet square on bottom, about 10 feet apart all
along one bent. The diggers were immediately set to work digging
around the piers just enough to permit the driver to lift the stones
out of the ditch with its pile line instead of the usual way of
having the laborers break up the stone and throw out to one side.
Occasionally a stone could be left in the ditch and the piles driven
around it. In another case the writer delayed starting the men
digging out some holes because he thought a day would easily clean
them out. However, on starting to dig the most complicated gril-
lage work on the job was found here, all embedded in concrete.
There was nothing in the lately ra ed building to indicate the need
of such footings, yet there they were - probably having been used
on some earlier building. The course of the driver had to be chang-
ed and instead of taking a day to clear out the holes, two shifts
of eight men each worked nearly a week before piles could be driven.

The question might be, and was asked by many, why could'nt
the old foundations be left in and utilized, making up any area
difficiency by concreting them in? This might be all right if
any of them came so that the pier tops would rest symmetrically

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upon them. However, none were symmetrical. Then too, the new foundations were designed for all the loads to be carried on piles, no dependence being placed on the soil. Again, the soil under the old footings had been already subjected to loads and was doubtless thoroughly packed and settled, whereas the adjoining soil had not been loaded and would in all probability settle when a load was placed upon it. This would mean uneven settlement of the footing, and consequent cracking of the concrete. At one time the writer was on the construction of a retaining wall which joined old abutments and ran on top of the old footings. In less than a year cracks developed over the end of the old foundation, due to uneven settlement, or perhaps a settlement of the new pile footings and none in the old. It can generally be accepted as very poor design to build a new structure partly on old and partly on new footings. The old walls and footings were gotten out by breaking the stones with sledges, raising the big stones a little so as to put a small block under them, then pounding away. Again, holes were drilled by two men with a sledge and a drill. After this steel bull points (a pointed piece of 1-1/2" steel about 2 feet long) were placed in the drilled holes and hammered upon. This was very bad as the wedge effect of the point was practically nothing after it was in about an inch. Plugs and feathers were then used, which, as always, proved very effective. Old concrete was surprisingly hard and took patience on the part of the men. The only effective method seeming to be that of putting two men with a sledge hammer breaking it out. The surprising part of this concrete was its strength. Put in years ago when not much stress was laid upon the
mixing and proportioning of the materials, it gives a fair idea of what the concrete of today, with its carefully proportioned aggregate, and method of mixing and placing, will be in years to come.

It was stated that the holes were opened up to make sure that there were no stones or obstructions to pile driving. This of course was a great advantage but not the greatest as by opening the holes a large amount of excavation around piles was avoided. With piles spaced as closely as they were, 2'-6" c. c. it is difficult to dig very deep after they are driven. In many cases where the piles were left five or six feet too high (reasons given later) they had to be cut off piece by piece so as to enable the men to work. It will be noticed by referring to the masonry drawing that 12" digging was allowed outside of a pile. This should be a minimum as the width of a shovel is about 12" and it is readily seen that it would be very tiresome to try and excavate less than a shovels width beside a pile. For this reason the holes were nearly always from 6" to 12" wider than planned, except of course, where the banks caved or sluffed in.

Not all of the excavation around piling can be avoided however, because of the upheaval caused by driving the piling. The amount of the upheaval varies considerably according to the nature of the soil. In the case in question the ground was a stiff heavy clay and in driving clusters of thirteen and sixteen piles the earth rose from one foot to 1'-6" on an average for the 12' x 12' holes. This matter is important when measuring the amount of excavation. One can readily see that for a finished hole 3 feet deep nearly 4'-6" in depth will have to be taken out. The effect of this upheaval will be considered in relation to pile driving.
The caving in of holes is a thing to be watched carefully. One can not be too careful about bracing the hole. Especially did this have to be watched where the holes were very deep and heavy banks of dirt piled on top and near the hole. Even with the holes carefully braced at the top one must watch clayey soils because they will crowd in at the bottom of the ditch if the soil is a little moist. It is common to hear excavators say, "don't let her start caving." In many cases tight bracing will hold up banks that have not started to move which would be snapped out quickly if an attempt was made to put them in after the earth started to slip. This point is more important in tunnel and caisson work, nevertheless we had examples of this on our work. One of the deep foundations was opened during frosty weather and braced only at the top, a warm day came, the earth thawed out and began to slip in at the bottom. This slip was enough to crack a 3'-0" thick concrete footing 12 feet from the hole. Extra bracing was put in and the hole filled with concrete, a 6 foot course the width of the hole being put in instead of one 3 foot course the width of the hole and then a narrower 3 foot course. This took extra concrete but kept the hole from caving and also saved carpenter work and lumber on forms which more than compensated for the extra concrete. The fact that a bank will stand in cold weather does not warrant leaving out braces if the hole is to be left open for any length of time, as the first warm weather will soon thaw out the earth, and the thawing frost acting as a lubricant soon helps the bank to slide and cave in.

PILE DRIVING:

It is estimated that there are over 11,000 piles in the founda-
tions of the part under discussion. To drive these two pile drivers of the type shown in Fig. 5 were used. These were equipped with the heaviest Vulcan Iron Works steam hammer which has a total weight of 5 tons and a 2-1/2 ton striking head with a drop of 3 feet, see Fig. 6. These drivers are very heavy and therefore great care must be taken when any amount of blocking has to be used so that the driver will not tip over. For this reason a great deal of the excavated material was hauled away so as to give a good clear road for the driver. The extra expense of hauling seems to have been warranted by the increased amount of work done by the driver, the increase amounting to as much as 90% in many instances. No attempt will be made to make any comparison between the types of pile driver hammers, for such the reader is referred to Baker's Masonry. However, the writer wishes to call attention to some advantages of the steam hammer over the drop hammer which are pertinent as they involve an important element, the saving of time. The steam hammer can drive piles without interfering with the running of the engine, this making it possible to pull piles to the driver, or drag in blocking without stopping the driving. This can be done with a drop hammer but not without much wear on the engine and great risk. Then too, the steam hammer is 12 ft. long and piles can be driven 8 to 10 feet below the bottom of the leads without using a follower, whereas, a drop hammer can do this for only a foot below the leads. These are simple points yet it is just such simple things that save time and labor. Another thing noticed by the writer while comparing two crews, was when piles had to be followed. One crew drove the pile as far as it could, stopped the hammer, raised it and then pulled in the follower, placed it on the pile and began driving again. The other crew was hauling in the follower, while the hammer was
being raised, they would also drag a pile to the driver while one was being driven and make everything ready for driving another pile. This same crew holds the record of this job, having driven 76 piles, 40 ft. and 45 ft. long, 3410 lineal feet, in less than 7 hours, and with medium hard driving.

The length of piles to be driven was determined by the Terminal Engineer, who decided on 30 ft. to 45 ft. piles. The latter of course being used for heavy loads and the others for light ones. However, in designing the footings, 15 tons per pile was the figure used, but in many cases this was increased to 20 tons where it was difficult to get a symmetrical arrangement of piles and a square footing. It can be seen that there are only certain numbers of piles which will permit of this. For instances 4 piles is the first number that gives a symmetrical arrangement and 5 piles next, six and seven do not give good arrangements, eight is fair, nine is good, thirteen and sixteen come next. Of course any number can be used if it is not desired to use square footings as was the case here. In this work nine, thirteen and sixteen pile clusters are the only ones used, and it will be seen that these give square piers. To carry 15 tons a pile, using the Engineering News formula \( p = \frac{2 \text{wh}}{l + 0.1} \), the penetration for the last blow must be 1 inch. However, this is misleading as much variation will occur in the driving of a single cluster. One pile may drive hard and the one next it drive easy, the latter probably being the longer pile. There are three conditions affecting this that have been noticed by the writer: first, - whether or not there is water around the pile, second, - the nature of the surface of the pile, and third, - the size and tapering of the pile. The first case is most interesting and was brought to notice when watching piles driven in a dry hole and seeing the
foreman throw a few buckets of water around them. With a view
to getting closer observation on this point I had one of my pile
recorders make notes on the effect of the water. He found that the
wetting of a pile would reduce the number of blows necessary to drive
the pile from one-half to two-thirds and that the penetration for
the last ten blows was increased the same proportion. Observation
was made of the effect of this surface wetting on different
kinds of surfaces, namely, - a smooth surface of a stripped tamarack,
the unbarked pine and maple or elm. At first glance one would say
that the effect would be greatest on a tamarack, growing less on the
piles in the order named. No so, however, the wetting was most
effective on the pine, then on the tamarack and next on the maple
and elm, although the effect for the first few blows is more effec-
tive on the tamarack. An explanation evolved was than the water
soon wore off of the smooth tamarack by the heat of friction, that
the rough bark of the pine had interstices or pockets just big enough
to hold the lubricant effectively without its being worn off, where-
as, the pockets of the rougher barked maple or elm were too large
and would not be filled sufficiently to overcome the resistance of
the rough bark.

The nature of the surface of the pile can easily been seen to
effect the driving in dry soil. The ease of driving varies in-
versely as the roughness of the bark. In our case the tamarack
drove easiest, the pine next and the maple and elm hardest.

It is obvious that a large diameter pile will offer greater
resistance than a smaller diameter pile because of the greater sur-
face exposed to friction of the soil. Then the more a pile tapers,
the greater the resistance to driving because earth has to be moved
aside the full length of the pile in the ground, whereas a uniform diameter pile has only the dirt at its tip to crowd aside.

Another important point is the effect of the pile setting over night, or rather the settling of the disturbed earth, upon the driving of the pile. The men on the driver being union men and very particular to quit on time gave ample chance for obser

this point, as often a pile was partly driven when the whistle blew and left to be finished the next morning. Two specific cases will be mentioned: A pile penetrating 7 inches in ten blows at 4:30 P.M. after setting till 8:00 the next morning only drove 3-1/2 inches in ten blows. Another penetrated 8 inches in ten blows at 4:30 P.M. and 2 inches in ten the next morning. Several other cases gave nearly the same results. It is easy to see that the bearing power of the pile as deduced from the formula would vary greatly according to which penetration was taken, the 7 inches in ten blows would give a bearing power of the pile one-half as great as the 3-1/2 inch would give, and the 8 inch, 1/4 of what 2 inches would give. Therefore it is seen that a great amount of reliance must be made upon close observation and personal experience. Probably the best way to do is to drive piles and test them by loading, but this is not always possible as the piles must be ordered long before any drivers are rigged up.

The upheaval due to driving piles was mentioned before and is a fact that should be kept in mind by every one doing pile driving. My first experience with the matter was brought about by a complaint. It was my duty to give elevations on a driver that was driving piles for the foundation of a wall and following them down far enough so that they would not have to be cut off. When the piles were uncovered it was found that they were too high and had to be cut off several
inches. Naturally I was blamed, so to try and exonerate myself I took levels on some piles immediately after they were driven also after adjoining piles were driven and found that they had risen. One of the engineers on the West Approach of the new C. & N. W. work also made some tests of this question. Some piles were driven and cut off. After a week or so pile driving was commenced 3 feet from them. The piles cut off were not disturbed at all, but the newly driven ones were raised 6" in some cases by the driving of piles near them. This is further evidence that piles set after standing, the earth settling back and getting a firm grip on the piles. One experience of the writer's on the work in question will show that the upheaval may prove serious. Piles were being driven in a cluster about 25 feet from a concrete pier. Levels taken before and after the cluster was driven showed that the pier of 548 Cu. Ft. weighing 41 tons, raised nearly 2", the corner nearest the driver being the highest as would naturally be expected.

Following piles has been mentioned. This is done whenever the pile is to be driven beyond the reach of the hammer or into ground. A short piece of pile, preferably oak, with a steel shoe and a ring on top is used and virtually makes an extension of the pile being driven. The follower being pulled out after the pile is driven as far as is required or as is possible. The last reason gives rise to the question as to how far a pile can be followed into the ground and permit of the follower being pulled out. This arose on this job as in some cases the cut off was from 3 feet to 20 feet under the surface. The nature of the soil makes a great difference. Loamy and sandy soil permits of driving 4 feet to 10 feet, but clay
offers a great resistance to pulling out because of suction. By making trials it was found that 16" was about the greatest distance a follower could be driven, and pulled out without making some special rigging to get more power than can be obtained from the usual single line run over one pulley to the engine. On one occasion the writer had the pile followed 5 feet into clay. It was not pulled out without breaking 1 inch lines with a single and double pulley and until a triple pulley was rigged up with a 1-1/2 inch line. The rigging up of these compound pulleys with the use of only single snatch blocks was very interesting and proves what was said before of simple things saving time. Ordinarily, the line to the follower is run over a single pulley, by fastening the hook some height up on the leads as at A Fig. 7a, and putting in a snatch block at B, a double pulley is rigged. Again by putting snatch blocks at A and B, Fig. 7b and fastening the hooks at end of the line and on block B together onto the object raised, a triple pulley is obtained.

It is important to keep a record of all piles driven for three reasons, namely, - to know how many lineal feet are driven; to know which piles are driven, as often some are driven below the ground and the holes filled by snow or mud washed in by rains; and to know the nature of the foundation under each pier in case of settlement after it is loaded. This latter point is the most important. On this work a pile recorder was stationed with each driver and it was his duty to see that the piles were driven in the proper places, that proper lengths were used and to keep a record of the piles driven. The latter embodied the following information: location, kind of wood, length, penetration during first and last ten blows,
amount followed, cut off necessary and date of driving. Not all of this record was required on every pile but on about four or five out of every pier. However, the location, kind, length and date was kept for every pile. In determining the amount of penetration the bottom 5 feet of the pile driver leads were marked off in inches and feet then by watching a knot or any mark on the pile and counting 10 blows, the amount was easily obtained. In the remarks on Laying Out it will be remembered the system of numbering bents and lines was explained; this was used to locate piers, then the north west pile in each cluster was number 1 and the remainder numbered as one reads a book. Wherever there were wall piles between clusters they were counted with the first cluster west. Sketches supplement this and show the scheme of numbering wherever any irregularity occurs.

At first the method of keeping this record was left to the recorders, and resulted in two methods. One kept the piles grouped that were driven each day, the other kept the pile grouped in clusters or as they were laid out on the ground. The latter method is by far the better. The former method is convenient when the amount driven each day is required. However, the chief object of the record as before mentioned is for future use, and it would be required to find a particular cluster of piles. It may happen that part of a cluster is driven several days or maybe weeks after some of the others were driven and it would be inconvenient to hunt through a record kept like the first mentioned for each pile in a particular cluster. One can easily see, therefore, the advantage of the second method, the method which was finally adopted by both drivers.

CONCRETE:

Having determined the number and spacing of piles required
in the foundation, the size of the bottom or footing of the pier is fixed by making the amount of concrete outside the center of piles at 1'-6". This amount leaves about 12" outside of the pile which as before mentioned, is about the least width it is possible to dig conveniently. Then as the size of the cast iron column base is determined when the loads are figured, and allowing about 6" extra on each side of the base, the top of the pier is fixed. Thus for a 4'-0" x 4'-0" base the top of the pedestal is made 5'-0" x 5'-0". With the top and bottom dimensions fixed the pier is designed so as to increase in size from the smaller to the larger dimension. This is done by building the pier in courses of increasing dimension, the increase in dimension, or offset as it is called, being a function of the height of the course. The offset is usually made about 1/3 of the height although some use 1/4, and should never be more than 1/2. With these determining factors it is a matter of judgment as to how to increase the pier. It should be done as quickly as possible and with the least height and the least number of courses; in other words with a minimum of concrete. The courses should, however, be of such a height that commercial widths of timbers can be used without being ripped to make the forms. It will be seen by referring to the general masonry plan Fig. 8, that there are three styles of piers, namely, - single column piers, two column piers and three column piers. By noticing where the different kinds of piers are located, it is easily seen that if an attempt to use single piers for every column had been made, that some of them would be very close, namely, - at the columns 12'-0" center to center, and in the J pedestals in bents 33, 34 and 35. Therefore
the piers as planned were decided upon so as to lessen the form work by making less cuts. If single piers were used for the two columns 12'-0" or 12'-6" c. c., six boxes or 24 sides would have to be used. As planned, however, there are only 4 boxes or 16 sides, and in these days of high priced lumber this is an important item. Then too, the skilled labor on the forms is lessened and the time of laborers placing concrete is substituted.

The nearest approach to a retaining wall in the section in question, is in bent 4, a section of which is shown in fig. 9. This, although retaining earth, resists the earth pressure more nearly as a beam, the floor at the top of the wall acting as an abutment as well as the footing. The column loads are very heavy on this wall and would counteract any tension due to bending. The wall being 4 feet thick, according to the theory that the width of retaining walls should be 0.4 of the height, would be good as a retaining wall 10'-0" high, whereas it is only 9'-0". The 4'-0" however, is determined by the column base. The only reinforcing, it will be seen, is the vertical bars at the junction of wall and footing to resists shear and the longitudinal reinforcing just above the piles. These latter bars are to resist the tension in the footing, due to considering the footing as a beam transmitting the column loads to the piles. For calculating the footing is taken as an overhanging beam, ending 1-2 way between the 26'-9" spaces, supported on two columns 12'-0" or 12'-6" c. c. and loaded by the piles. Allowance is made for continuity by taking $M = \frac{1}{12} \text{wl}^2$, instead of $\frac{1}{8} \text{wl}^2$ or $2/3$ the moment figured as a single beam. The straight line theory of reinforcing concrete is used entirely.

Why couldn't piers have been built here as at other places
and the wall built in between? This would have saved the footing reinforcement and a lighter reinforced wall could be used. However, it is desired to have as much of the room possible south of bent 4 available for a basement, and as it is also desirable to have a straight faced wall, one free from pilasters and nooks made by them, the piers would have to be below the top of the basement floor. This being at elevation of +3.0 and the piers 9 feet deep would require digging to an elevation of -6.0, whereas the present arrangement only requires digging to about elevation -1.0. When it is remembered that the deeper excavation is the more expensive, one can see a great advantage in the wall as designed. Then too, the pier arrangement would require more concrete. It will be interesting to note the method used to find the earth pressure although it did not determine the design of the above wall. The amount of the earth pressure is taken as $15H^2$ applied horizontally at a point $2/3 H$ from the top of the wall. This quantity is deduced from Rankine's formula for earth pressure and is shown in fig. 10.

By referring to fig. 15 which shows the platform it will be seen that it is made up of reinforced concrete slabs. The design of slabs is still a mooted question. Then too, all discussions known to the writer consider the slabs as uniformly loaded. The slabs were first designed for a live load of 120 lbs. per sq. ft. and a dead load of 140 lbs. per sq. ft., then it was desired to investigate for a concentrated load of 6000 lbs. on two axles 6'-1" c. c. with wheels 3'-0" c. c. such as would be obtained from bagge trucks. The only thing giving help was Turneaure and Maurer's Reinforced Concrete. This considers the slab as elements at right angles to each other which naturally have a common deflection at
Derivation of Formula (186)

By finding the unit pressure of water at a point where \( w_0 \) is the weight of water at the surface, \( r \) is the distance of the point to the origin, \( u \) the unit pressure on the surface, and \( n \) the angle of incidence.

Our work in a usual case is to find the total pressure in solution to the point. Each \( n \circ \) and \( u \) applied at \( \frac{n}{2} \) below the surface.

\[ \text{Fig. 10} \]

This corresponds to the point of the center of a circle to determine the center of the total force by the sum of the elements at right angles to sails, 4.2.47 under the land.

A reflection causes two and it is true.

For each element, \( F_1 \) and \( F_2 \) (\( \text{Fig. 11} \))

\[ \text{Fig. 11} \]
their intersections. By considering the deflection of two elements in the center of the slab and at right angles to each other the amount of load taken by each element was determined and designed for this amount. Fig. 11 shows how this load division was found.

The reinforcement of the train shed roof is the suggestion of the General Fireproofing Company. From previous tests they say that the gauge of their trussit used is good for a 2-1/2" slab of greater dimensions that the largest in this roof. This gives a thin, and at the same time a strong roof. The loads used in designing the roof were, snow 20 lbs. per sq. ft., skylight 10 lbs. per sq. ft., concrete 30 lbs. per sq. ft. and steel 10 lbs. per sq. ft.

It is every necessary to have the track level floor waterproof for the protection of the rooms below. The 12" of concrete between the steel is designed to carry a derailed train. This thickness is great for these short spans and lessens the tendency to crack. Then 1-1/2" of a waterproofing mixture is applied to the top which, in the ballast floor is covered with bricks for a protection from the cutting of the ballast.

The question of waterproofing is a much discussed one. There are several methods but they may be divided into two classes, namely, - those which consist of an elastic substance and those consisting of a powdered substance. The latter consists of compounds either mixed with the concrete or applied as a mortar to the face or back of the wall after the form is down. The elastic waterproofing substance consists of a plain asphalt mastic, asphalt covered burlap, or a felt saturated with an asphalt mixture. These last are sometimes called membrane methods. There is no doubt that the imperviousness of concrete increases as its density increases.
Also that the denser the concrete the less the amount of voids.
The functions of the powder waterproofings is to decrease these voids, by mixing them with the concrete or by forming a skin over the face. The face to which the waterproofing is applied being the one nearest the source of water. There is no doubt that there are cases where these last named waterproofing substances have been successful but they are where the concrete is well reinforced against temperature cracks or where there has been practically no settlement, because if this were not so, cracks will develop and as the substances do not flow, their efficiency is destroyed. In the Illinois Telephone Company's concrete tunnel in Chicago, the inside is covered with a mortar of one part powdered stone and two parts Portland cement. This mortar is put on by plasterers who work the material on filling the pores thoroughly and after partially set is washed down with brushes. It sets extremely hard, and so far seems to be effective as a waterproofing substance. Another plan used in Chicago and said to be successful is to put on a coating of Star Stetton cement as soon as the forms are down and before the concrete dries out.

The membrane method seems to be the most effective, because the elasticity of the materials allow them to stretch, and within the limits of elasticity of the substances will not crack when the concrete does. Two methods used are the Hydrex and Sarco. The first consists of felt saturated with an asphaltic mixture. Usually a thin layer of concrete is put on top of the felt for a protection. The objection to this felt is that it is not pliable enough to adapt itself to irregularities and is likely to crack. Then too,
it is hard to lay so that it will be smooth and the different layers adhere, in other words it is hard to avoid air pockets. Sarco is a form of asphalt and is laid on as a mortar about 1-1/2" thick. Wherever cracks are likely to appear a piece of burlap cut diagonally to the mesh and saturated in Sarco is put on. It is claimed that the diagonal cutting adds to the elasticity of the substance. There is an objection raised by some to the burlap because of its being of vegetable origin and liable to decay. This objection is also made against asphalt and experience in Chicago seems to warrant it. Care must be taken to have the material of sufficient plasticity at all temperatures so that it will not be too hard in winter and crack, or too soft in summer and flow away.

So much for the design and now we will consider the construction. As the piers were designed to take all of the load, no reliance being placed upon the earth, in putting in the footing or bottom course care was taken to see that the outside piles had at least 12" of concrete outside of them and that the holes were well shaped. No forms were put in the bottom unless the hole had caved in too much then planks were simply laid on edge as the concrete was placed. Forms had to be made for the other courses, excepting, however, for the piers of four courses. It can be seen that these piers required deep digging, their bottoms being below datum or 8 feet below the surface of the ground. As mentioned while discussing excavation, these holes frequently caused anxiety if not trouble by their tendency to cave. Therefore in all of these piers the first two courses were made into one, that is, the holes were filled up to the top of the second course. This saved form work and also eliminated more quickly the danger from the hole caving.
At first the carpenters made the forms of 3" timber, making the sides of the boxes so that they would be handled as one piece, then nailing them together in place. This was open to two objections: First, the lumber was too heavy, 2" material being thick enough; second, the nailing of the sides together made it hard to take the forms off when the concrete was set and almost impossible to do so without destroying the lumber. For this reason 2" stuff was used, and assembled as shown in fig. 14. This consists of nailing to each side of a box two 2" x 8" planks, flat side horizontal, one near the top and one near the bottom, and long enough to extend about a foot beyond the ends. These pieces were nailed at such height so that when the sides of the box were put together two sets rested on top of the other two sets. Holes for 7/8" bolts were then drilled and a bolt put in to hold the sides together, and by simply knocking out the bolts the forms are easy to take apart. Of course the boxes have to be braced so that they will not be moved from the proper position when the concrete is thrown in. This bracing can be seen in the figure referred to above.

These boxes were set accurately to lines given by the engineer, who set points on templates, boards or profiles. These are all the same thing and consist of two stakes driven into the ground sticking up high enough to nail a cross piece to at right angles to the line being marked, and above the top of the pier. Several of these are put upon on each line and the points set on the cross piece. After the box is placed the top of the concrete is marked, approximately in the middle courses, but accurately in the top box by setting nails.

Some trouble was had in trying to finish the piers to the
exact height. This is due to the shrinkage of the concrete, a quantity depending upon the moisture of the concrete and the condition of the weather, which are both so uncertain that no allowance for shrinkage can be made. Now, however, the work is so arranged that the top of the piers are always finished so as to give time to partially set before the finisher finishes the top. Even then these heights are not always correct. However, a 1/2" cement joint is allowed for under the column bases so that any little discrepancy can be made up in this joint.

Mention was made of bracing forms to keep them from moving. This is important, especially where there is just room enough on top of the wall for the bearing parts, and where a good line is desired. It is more difficult to keep the high forms lined up because of the impact of the concrete against the forms increasing as the height of the drop increases. Forms braced to stakes driven in the frozen ground had to be watched in thawing weather and in some cases had to be reset. To help prevent the bracing giving out, the sides of the forms are wired together. This consists of putting a wooden separator between the sides of the forms to insure proper width then a wire around opposite uprights is wound around, and with the aid of a stick the wire is twisted together and the forms drawn right up against the separator. The separators are knocked out as the concrete reaches them, and after the forms are taken down the wires are cut off as far into the concrete as is possible without disfiguring the face too badly.

Another method is to bolt the sides of the form together. Generally 7/8" bolts are used and are put through an inch or an inch and one-half pipe which is cut and placed so that its ends are
about 2" from the face of the wall. This pipe is employed so that the cement will not adhere to the bolt and prevent its being pulled out, and is cut short so that it will not be seen on the face of the wall. Waste is plugged into the ends of the pipe and around the bolt to prevent the cement from running into it. When the forms are to be removed these bolts are taken out by first twisting them so as to loosen them from the 2" of concrete on each end, and then pried out by levers for a short distance. Then a driving head is screwed onto the bolt and by hammering this the bolt is removed.

In my opinion the latter method is preferable because in observing walls where wires were used I have noticed that in time the wire ends become exposed and rust causing the face of the wall to become spotted and streaked. Perhaps if care is taken to cut the wires as soon as the forms are taken off and the holes carefully pointed up while the concrete is still damp this might not occur. Care must be taken when rods are used to see that the holes are filled with cement for some distance from the face. If this is not done it is obvious that water is likely to seep through from the back and disfigure the face. In most cases on the work under discussion the walls are exposed and as it is less expensive the wire method is used.

As the majority of the concrete on this work is covered up, rough lumber is chiefly used for forms; however, where the concrete is exposed, surfaced tongue and groved lumber is used. It is necessary to see that the face of the form is smooth and this is not always insured by using tongue and groved stuff. On the work under discussion this had to be watched as not all of the lumber was center matched, some of it having the tongue and groove off
center. A seemingly small but quite important thing is to see that no nails are left in the face of the forms. On high walls carpenters are very likely to drive in nails on which to hang their saws and forget to pull them out. One can easily foresee the result.

Gravel concrete is used throughout this work, the gravel coming from the company's pit at Cary, Illinois. At first this gravel was washed and screened, everything passing over a 1/4" mesh and the concrete made in proportions of 1 - 2-1/2 & 5. Now, however, pit-run gravel is used and in proportion of 1 - 4. In determining the voids of the sand by the water volume method it was found that the pit-run gravel had more voids than the material passing over a 1/4" screen, the former being 28% and the latter 21.5%. Universal Portland cement is used throughout the entire work.

At first two kinds of concrete mixers were in use, the Drake and the Ransome mixers. The first consists of blades fastened to a shaft about 6 feet long revolving in a semi-cylindrical trough. The dry materials are placed in the trough at the machine end and driven forward to the discharge. Water is supplied from a perforated pipe running along the top edges of the trough. The arrangement of this machine is shown in fig. 12. This machine was not very effective and finally abandoned in favor of the Ransome. No description of this mixer is necessary as any engineering periodical advertises and illustrates it, and also because one of them is shown in fig. 13. The arrangement of mixers is an important item in that on the arrangement depends the facility with which the concrete is mixed. As a general rule it may be said, that the materials
should be put into the mixer with as little handling as possible. Referring to fig. 12, the method of delivering to the Drake mixer is seen. This method is very poor in that the material has to be lifted about 3 feet with shovels from the platform into the mixer. This handling could be eliminated by having the platform on a level with the top of the trough or even better, by having a hopper at the machine end and dumping the wheelbarrows directly into it. Then with a trap door arrangement the materials could be fed to the mixer as needed. With the mixer arranged as shown 24 men hauling about 100 feet put in 40 yards of concrete in 8 hours at a cost of $2.38 per yard.

Fig. 13 shows a Ransome mixer, and illustrates the method of delivery advocated above for the Drake machine. Here the materials are dumped directly from the wheelbarrows into the machine, and water is fed by bucket, insuring a more uniform mixture. The materials are turned for about 6 revolutions and then discharged into wheelbarrows by turning the scoop, shown on the right of the machine, into the mixer. With this machine as shown 24 men hauling 250 feet put in 61.1 yards of concrete in 8 hours at a cost of $1.61 a yard, and with a haul of about 65 feet 102 yards were put in. However the average output on a haul varying from 75 to 80 feet is about 85 yards. The output of this machine would be increased if the concrete could be taken from the mixer at one dumping, that is emptying the machine as quickly as possible into cars of the same capacity as the mixer and running on tracks to the forms. The writer has timed the operation of mixing and where eight wheelbarrow loads of gravel and four sacks of cement
were delivered to the mixer it took one minute to deliver and two minutes to discharge, 13 wheelbarrows being necessary to haul away the concrete because the wetness made it impossible to fill the wheelbarrows. By using cars as mentioned above the time of discharge could be cut down to 30 seconds, thus doubling the total output. Before leaving this machine it will be well to mention a method of using it which cannot be too severely condemned. This is not having the run up to the feed, but dumping the dry material on the ground level and then lifting it up with shovels about five feet into the machine.

The motive power on all of the machines is electricity, direct current motors of 15 to 25 horse power being used. These machines take up but very little room and are much handier and cleaner than the usual boiler and engine.

By elaborating on the arrangement of the methods of delivering to and taking from the machine the output can be increased very much. In one arrangement the output averages 190 yards in 9 hours, another 300 yards in 10 hours, both with about 20 men, the latter having a record of 390 yards in 10 hours. With a machine made by the Municipal Engineering Company, 135 yards were placed in 5 hours with 13 men. These plants, however, are on other sections of the work so will not be further discussed.

As is most generally done at the present time, the concrete is mixed wet enough so that the men spreading it sink in to their knees. This does away with tamping, as the men walking in the concrete churn it up, letting the air escape and insuring a more dense concrete. On all of the work that will be exposed the concrete is given a spaded face. Some very satisfactory work was done this
way, in fact some of the best finish I have ever seen was spaded finish. On the retaining walls of the other sections, cement mortar is plastered against the form and kept 6 to 10 inches higher than the concrete which is thrown against it. The tops of piers are not trowel finished but struck. This is done in order to obtain a rough finish, which will bond better to the mortar joint under the castings.

In freezing weather the sand and gravel is heated. This is done by piling the materials on and around 30 inch steel cylinders in which are built wood fires. Originally it was intended to use the materials unheated and also to put in concrete that would eventually be covered up until the weather became too cold for the men to work. The justification for this being that freezing does not materially injure concrete, its effect being only to retard the set of the cement and cause a slight peeling of the face. However, as the materials came frozen up in large lumps, the fires were adopted. An objection raised to heating the materials is that the water is dried out before crystallization takes place, but with lots of water it is probable that the materials are chilled again before they leave the mixer. Then too, it does not take much water to cause cement to set, and the heat of the materials cannot evaporate all of the water. However, concrete that was to have a finished face was not placed in weather colder than 25° F. and all concreting stopped at 15°.

Another precaution taken in cold weather is that the concrete is covered with tarpaulins and the forms left on four to five days, whereas in warm weather they are taken off thirty six hours after concrete is placed. Manure is used quite extensively
it would have to set on top of the column and knee braces perpendicular to the beam would have to be employed in order to obtain a
for covering concrete in such cases, but being dirty and unhandy to remove is objectionable.

STEEL:

As the steel will not be delivered to the work being considered before June, only the design can be discussed. Fig. 15 shows the typical design of the floor and shed, and fig. 16 shows in detail some of the irregularities of the floor. For convenience of discussion this topic will be divided into two divisions: the floor design and the shed design.

The reasons for having the track on a steel structure have already been mentioned so it will not be necessary to give them again. Referring to fig. 16 it will be noticed that in general the transverse portion of the floor consists of overhanging track carrying box girders and suspended platform beams, with the columns in the center of the tracks. This arrangement is the most economical because long simple spans are avoided, and the bending moment is reduced to a minimum, the only live load movement being from one rail. If simple box girder beams had been used their deflection would cause a movement at the joints which in time would loosen the rivets in the end connections. If single web girders were used there would be the same loosening and in addition tension on the rivets. In the design adopted, however, the elastic curve is always horizontal at the columns, and therefore there is no movement or tendency to destroy the connections rigidity. The box girder is the only one which can be built as an overhanging beam and have the rigid column connections shown. To use a single web overhanging beam it would have to set on top of the column and knee braces perpendicular to the beam would have to be employed in order to obtain a
rigid connection. This could not be done without much work because the column is between the longitudinal stringers to which connections would have to be made, and also not without reducing the headroom below. Another advantage of the box girder is that the drainage pipes are concealed and can be easily carried to the column.

It may be seen that the top flanges of the box girders are turned in and the lower flanges turned out. The top flange is turned in so that the tops of the stringers and floor beams can be flush without coping the top flange of the stringers. The bottom flange is turned out so that it will not have to be cut in order to admit the column and also to permit an entrance between the webs for riveting, painting and putting in drain pipes. Diaphragms are placed at all stringer connections so that the load will be distributed to both webs and flanges making them act as one girder and being designed for floor beam reactions. Without the diaphragms each web and its flanges would be treated as a single girder designed for end shears of the stringers. This would require more web section as one floor beam reaction is less than two shears. With diaphragms two webs of minimum thickness is sufficient but one web of the same thickness is not enough if treated as acting alone. Of course the diaphragms require extra material but not as much as is saved in the webs when considering them acting together. However, the greatest advantage of the diaphragm is that an unsymmetrical girder with a tendency to buckle and tear the column connection rivets is avoided and a more rigid structure obtained. The remainder of the floor consists of simple girders, but attention is called to the arrangement of the platform curb girders, and the method of caring for transverse expansion at their connections.
In calculating these girders and the floor the possibility of a train being derailed is considered, however, where this is done, the allowable stresses are increased one-third. With the thickness of concrete shown a very strong floor is obtained and with an asphalt covering should be water proof.

The rails are carried on longitudinal timbers fastened to the stringers. As a result of this the floor is open and can be cleaned more expeditiously than if cross ties were employed. The floor being easily cleaned facilitates the drainage and lessens the danger of leakage. Then too, a more elastic track is obtained, than if the rails were fastened directly to the steel stringers. And again, the timber affords good insulation, a condition very desirable because of the electric currents in the rails for the interlocking and block systems.

What has been said above refers only to the floor in the shed. In the ballast floor section the same general plan of floor beams and stringers is maintained. However, all the floor or transverse beams are the same depth and at the same height across the building. The reason for this is obvious. Another difference is that bricks are laid upon the waterproofing to protect it from the ballast which has a minimum depth of 6 inches under the ties.

Because the stringers in the ballast floor are lower than those in the shed floor, the floor beams at the junction of the two floors are special in that they are deeper. Fig. 16 shows the details of these beams. Fig. 17a & b shows a typical column and column base. For uniformity all the columns are 2 - 15" channels, 12 inches back to back with a four angle and plate diaphragm. The bases are figured to give a pressure of 400 lbs. per square inch on
COLUMN

3" Pitch for 3" 4½" Pitch

- 12 x 2½ pl.
- 2 x 4½ x 2½
- 21 x ³/₈ x 2½ pl.
- 12 x ⅞½ pl. about 4½ c.t.c.

Fig. 17(a)
Cast Iron Base B

Core holes for 1\(\frac{1}{4}\) x 12" Anchor Bolt. Sq. Nut: Plain end, 3\(\frac{1}{2}\)" thread.

3" reamed hole in bottom

Holes for 7" Bolts drilled.

Casting to be planed:
Top and bottom

Grouting

Concrete

2'0"

2'0"

10" 10"

7"

11"

11"

7"

30"

10"

5"

FIG. 17 (b)

3
the masonry and are made large enough on top to insure a good connection to the column. Then by considering the casting as an inverted overhanging beam supported at the two quarter points of the column sole plate, and loaded uniformly by the pressure on the concrete the casting is investigated for strength. The formula SI = Mc is used, the allowable tension being 2000 lbs. per sq. in.

All of the track floor steel is designed for Cooper's E50 loading. The allowable stresses are 15,000 lbs. per sq. in. for tension and compression and 9,000 lbs. per sq. in. of gross section for shear. The usual impact formula is \( \frac{L}{L + D} \) where L and D are respectively the live and dead load stresses. However, because the trains will run into the station at slow speed one-half of the usual impact is used for the steel and one-fourth for the masonry and footings. Rankine's column formula was employed. Wherever two or three tracks were loaded the live load stresses were taken as 80% and 75% respectively of the stresses obtained from the full loads.

To care for the longitudinal expansion, expansion joints are placed in the center of Washington and Randolph Streets and at the south line of Lake Street. Figs. 18 and 19 show the typical expansion joints which explain themselves. The cross lining sloping up from left to right is asphalt, and the other cross lining being concrete.

The sheds known as the Bush Shed, named after its inventor Mr. Lincoln Bush while Chief Engineer of the D. L. & W. Ry. The following is taken from a pamphlet prepared for the Mississippi Wire Glass Company by Peter Joseph Mc Keon, after consultation with Kenneth M. Murchison, Architect and Lincoln Bush, and in conjunction
Section "A-A."

Holes for 8 turned bolts

Section "E-E."

Holes for 8 turned bolts

Fig. 18(b)
Curb Girder Expansion - Outside Platforms

Fig. 19. (a)
\[ \frac{L}{3} \]
with figs. 20-21 and 22 serves to describe the general plan and its advantages.

The advantages of the Bush Train Shed as erected at the Lackawanna Terminal, Hoboken, are excellent light, freedom from smoke and gas, abundant ventilation, and a general sanitary appearance. In addition it has been found, after nearly two years service, that the temperature during the summer months is from three to five degrees lower than in the high arch type of train shed under similar conditions, while it is very noticeable that the annoying echos found in the high arch type of shed are eliminated in this type of construction. In the cost of material, erection, and maintenance the Lackawanna Train Shed presents some interesting figures. The actual shipping weight of metal in this train shed was 20.09 lb. per square foot of the entire area covered, a weight which is about forty per cent less than the weight of metal in the ordinary high arch shed. This saving in material represented a large amount of money, when it is considered that this shed has a roof area of two hundred and eight thousand, seven hundred and eighty five square feet. There is also a very material saving in the reduced cost of erection, as the Lackawanna Train Shed was erected entirely by means of an ordinary derrick car, with no false work whatever, while the old type of shed, with its long high spans, has to be supported on false work until the truss connections are made. The work of erection was also more easily carried on. In nearly every location, where a new train shed is built, it has to be erected on a site where passenger traffic is accommodated, and the handling of structural material on the high false work necessary for the old type of shed increased materially the liability of accidents to the
traveling public underneath. In erecting the Lackawanna Train Shed, it was necessary to take possession of only two tracks at any time while the work was in progress, and at no time was the steel work handled over the traveling public. The Lackawanna Train Shed also represents a great saving in the maintenance cost of the steel work as compared with the old type of train shed. This is due to the fact that engine gases are discharged directly into the open air and do not come in contact with the steel work at all.

Another practical advantage of the Bush Train Shed is that it can be carried up to the face of the railroad station building, without interfering with the light for the offices in the building.

The Lackawanna Train Shed at Hoboken is noteworthy for its excellent light. On a sunshiny day the shadows of the columns supporting the roof of the shed can be easily seen on the platforms, a circumstance that shows this shed to be very superior to the high arch type of shed from the standpoint of light. There are two continuous lines of skylights, each seven feet, ten inches wide over each twenty foot platform, and one continuous line of skylights, three and one-half feet wide, with a ventilated ridge on the center line between the tracks. The total area of all skylights is eighty-eight thousand, seven hundred and ninety-two square feet. The skylights over the platforms furnish abundant light for the platforms as well as to the side of the cars standing next to the platforms. The skylights on the center line between the tracks give very good light to the windows of two lines of cars standing on the two tracks between platforms. Any one in the cars can easily read by the light coming in through the skylights. In the high arch type of shed, the skylights are in most instances from
sixty to seventy feet above the platforms and always covered with soot and dirt. The small amount of light that does penetrate them has to travel many feet through air filled with smoke and gas, which reduces the light from the skylight.

The roof of the Lackawanna Train Shed is very accessible for painting, cleaning, or the removal of snow, if this should be necessary. As a matter of fact, no cleaning whatever has been done on the skylight glass since the shed was constructed, as dirt or smoke did not accumulate on the glass. During the winter of 1906-1907, no snow whatever was shoveled from the roof or the skylights, although four heavy snow-storms occurred, and according to the Weather Bureau Report, there was one snow fall of ten and one-half inches, which was accompanied by high winds, and during which snow fell for about thirty hours. There was also another fall of snow which, according to the Weather Bureau Report, amounted to about four and one-half inches, and the press statements indicated that the snow fall during the winter of 1906-1907, in the vicinity of New York exceeded any previous snow fall within a period of twenty years. Even with the ten and one-half inches of snow, reasonably good light came through the open smoke ducts, and afforded sufficient light for the Train Shed. Were it found necessary to shovel snow from the roof of this shed, the smoke ducts will greatly assist in such an operation as the snow would not have to be rehandled, but could be thrown into the smoke duct and dropped in gondola cars placed on the tracks underneath the smoke duct opening. During the snow storms mentioned very little snow reached the platforms; with a maximum fall of ten and one-half inches, mentioned above, there was not more than three-eights of an inch of snow on any of the platforms. The drainage from the roof of the Lackawanna Train Shed
is conducted down wrought iron drain pipes, placed inside of the cast iron columns, with an insulating air chamber between the inner shell of the cast iron column and the outside of the drain pipe. This reduces the liability of water freezing in the drain pipes, and also places the drain pipes in a location where objectionable appearances are entirely eliminated, as well as the danger of the drain pipes being knocked down by baggage trucks.

The operation of the smoke ducts in the Lackawanna Train Shed at Hoboken, is shown by the illustration. In the center of the roof over each track is a trough or horizontal duct, through which the locomotive smoke stack runs, once the locomotive enters the train shed. It is built of a pair of light lattice-stringers, which are wrapped with expanded metal and encased solidly in concrete, the surface being floated smooth. The portion of each main girder where it crosses the opening is also encased in concrete, so that smoke and gases do not come in contact with any steel work. The smoke ducts have been found to keep the train shed clear of steam and smoke, and since the yard was enclosed, there has been no appearance of offensive odors from engine gases. The smoke ducts have an effect similar to a moderate draft of a chimney and the exhaust from the locomotive stack instead of being discharged under the shed, is thrown out above the top of the shed and into the open air. This exhaust from the bottom of the smoke duct causes a vacuum, as it were between the walls of the smoke duct and fresh air is drawn into the space, thus producing regular ventilation. In the wall of the smoke duct, there are also small openings about two inches wide by fourteen inches long, immediately under the concrete roof, which permit any gas which might get behind the smoke duct.
construction, or any heat arising from the platform, to at once escape into the open air through the smoke duct. The volume of air in the Lackawanna Train Shed is about one-fifth of the volume of air in the ordinary type of high arch shed covering the same area, and this smaller volume of air is renewed much more frequently. The smoke ducts are so arranged that a driving storm cannot strike the platforms, the smoke ducts being two feet six inches wide in the clear and carried about one foot three inches above the top of the roof and two feet four inches below the under side of the roof. In the worst storm there is not a large amount of rain that comes through the smoke duct on to the roof of cars, but whatever rain does come through strikes the top of cars and falls between the cars and the nearest edge of platform, the track centers being so located that the drip from the eaves of the car misses the edge of the platform.

By comparing the views of the D. L. & W. Ry. shed with the shed shown in fig. 15, it is seen that there is not much difference between the two. The latter weighs 19.0 lbs. per square foot, and the former 20.9 lbs. per square foot. This is because the spans are different, the D. L. & W. Ry. being 43'-4-1/2" and the C. & N. W. Ry. 39'-3"., and because the loads are distributed differently. In the D. L. & W. Ry. shed the purlins carry the roof loads to the trusses. In the C. & N. W. Ry. shed the purlins carry the loads to rafters, which carry them to the ducts and longitudinal struts at the columns, the trusses getting only four concentrated loads and a uniform load from the space between the truss and the nearest rafters. The duct with a lattice of minimum sections permissible makes a stiff reinforced concrete beam, and the longitudinal strut also
with minimum sections is abundantly strong. The loads used were, Snow 20 lbs. per sq. ft., Skylight 10 lbs. per sq. ft., Concrete 30 lbs. per sq. ft. and Steel 10 lbs. per sq. ft.

The line of the intrados was determined by fixing the heights of clearance over the platform and the highest locomotive stack or cab ventilator. A five centered arch was then constructed which coincided with these points and gave a pleasing line. With the pitch of the roof, and the minimum depth of truss determined after much figuring, the roof line was chosen. The curvature at the ridge keeps the roof below the top of the ducts preventing a down draft and maintains a good pitch. By making the duct higher the curvature need not have been put in, but the height of duct chosen was considered the maximum height feasible.

There was much discussion and calculation in deciding how the trusses should be designed, that is, whether they should be considered as fixed arches, fixed beams or simple beams.

The fixed arch is statically indeterminate and at best there is much uncertainty as to the location of the linear arch and its abutments. Any yielding of the supports changes the amount and direction of the thrust and consequently the stresses in the arch. Professor Merriman says: "Only in instances where abutments of solid rock are at hand and where the traffic is very heavy can the use of the statically indeterminate forms be regarded as legitimate in theory and satisfactory in practice." If this be so, how far from being legitimate and satisfactory would be a fixed arch with columns as abutments. The elasticity of the column will cause a varying linear arch. Of course there is a certain deflection of the column which will balance the horizontal component of the thrust, and which
by a number of trials can be determined. But with nine arches each will have its own thrust, which at times will be variable because of the irregular loading of snow, and each thrust will deflect the columns. One can see that there would be much uncertainty of this structure as a fixed arch, and it was sufficient to cause the fixed arch design to be abandoned.

In considering the trusses as fixed beams the bending moments at all the supports must be equal in order to prevent deflection of the columns. This would require a very rigid end column at the side span. However, it was found that if the side span was considered as a cantilever without the snow load a moment was developed at the second column from the side which equaled the moment necessary to fix the adjoining span. Therefore the outer bearing of the side span was made low an amount slightly greater than the deflection of the truss acting as a cantilever without the snow load.

Wedges were then provided to be driven between the bearing and sole plates just to insure bearing without taking any load. Any extra load would set up simple beam action without changing the bending moment at the support adjoining the next span. This method requires that the trusses be rigidly tied together to care for flange stresses. To do this, bent plates were fastened to the top of the columns and top flanges of the trusses. These prevented a simple straight drainage down the inside of the column. The straightness required for ease of cleaning and repair, and the location desired so that the down-spout would be partially hidden from view, adding to the aesthetic part of the design.

Either one of the above designs would result in a lighter
structure than if designed as a simple beam because of there being inflection points and smaller bending moments. However, the objection to the drainage was great enough to offset this advantage, so the trusses are calculated as simple beams.

Figures 23 and 24 show the expansion joints for the roof. The arrangement for the duct is a simple one of pins and links. The chief difficulty in these joints is to keep the roof waterproof and care must be taken to protect the openings. This is done here with the use of copper plates and inverted concrete troughs.

As said before the erection will not commence until next June, so that no discussion of it can be given here. However, it may be well to mention the expected method of procedure. First, the castings will have to be set accurately to line and grade, then the columns will be set, the track carrying and platform beams being placed on the columns as soon as they are up, after this the longitudinal stringers will be placed. This will allow tracks to be laid on top of the steel and then the erection of the trusses.

There are still many more things to be done before the shed will be ready for occupancy such as, concreting platforms and roof, laying of track and installation of the interlocking system, but limited time forbid going into minute detail. Therefore I chose the parts of larger interest.

In closing I wish to acknowledge the kindness of Mr. W. C. Armstrong, Terminal Engineer of the Chicago & North Western Railway Company for giving me permission to use drawings for photographs, and also the kindness of Mr. Lincoln Bush, Consulting Engineer, New York, for giving me the views of the Hoboken shed of the Delaware, Lackawanna & Western Railway Company.