2020

Modern Engineering

William Jarvis McAlpine

MODERN ENGINEERING

By

William Jarvis McAlpine

Engineering

LIVRE DE LYON

Lyon 2020

To John B. Jervis, Esq.,

Honorary Member of the Society of Civil Engineers, etc., etc.:

Dear Sir—I was appointed, by you, a rodman on the Carbondale Railway, just fifty years ago, and continued to serve under you for sixteen years.

Your exceeding kindness, and the invaluable instructions which you gave me in my profession, necessarily secured my warmest gratitude.

Your friendship has been extended to me down to the present time, and is now evinced by allowing me to dedicate to you this address on " Modern Engineering," a work which you examined and advised upon, in manuscript, and was pleased to approve.

Your eminent services, exalted talent, and long career in the profession, have earned for you the title of its Father in this country, and renders it peculiarly appropriate that this tribute of gratitude, affection and respect, should come from your oldest living pupil.

Very sincerely, yours, etc.,

Wm. J. McALPINE.

Albany, *April 30th*, 1874.

In 1868, the American Institute resolved to have a course of twelve scientific lectures delivered in New York, and selected therefor the following gentlemen and subjects:

1st. By Rev. F. A. P. Barnard, LL.D., President of Columbia College of New York, "On the Microscope and its revelations." Wednesday, November 25th, 1868.
2d. By Prof. Stephen Alexander, of Princeton College, New Jersey, "On the Telescope." Friday December 4th, 1868.
3d. By Prof. GUYOT, also of Princeton College, " On the Barometer." Friday, December 11th, 1868.
4th. By Prof. Benjamin Silliman, of Yale College, Conn., "On the Philosophy of the Tea Kettle." Wednesday, December 16th, 1868.
5th. By Prof. I. W. Dawson, Principal of McGill College Montreal, "On the Primeval Flora." Wednesday, December 23d, 1868.
6th. By Prof. James Hall, State Geologist of New York, "On the Evolutions of the North American Continent." Wednesday, December 30th, 1868.
7th. By Prof. E. N. HOSFORD, of Cambridge, Mass., "On the Philosophy of the Oven." Wednesday, January 6th, 1869.
8th. By Doctor T. STERRY Hunt, of Montreal, Canada, "On Primeval Chemistry." Wednesday, January 13th, 1869.
9th. By Prof. R. Ogden DOREMUS, of the College of the City of New York, "On the Photometer." Friday, January 22d, 1869.
10th. By Prof. B. Waterhouse Hawkins, of London, England, "On Comparative Zoology." Wednesday, January 27th, 1869.

11th. By Prof. I. T. Cook, of Harvard University, Mass., "On the Spectroscope." Wednesday, February 3d, 1869.

12th. By Hon. William J. McALPINE, of New York, President of the American Society of Civil Engineers, " On Modern Engineering." Wednesday, February 10th, 1869.

On the last evening, before the lecture was delivered, the Hon. Horace Greeley, the President of the Institute, made the following address:

Ladies and Gentlemen: The American Institute, disappointed in being able in the year lately closed to give such an exhibition of the products of American industry as it deemed fit or worthy of its own reputation and high character, postponed that exhibition to the year on which we have now entered; and, instead of it, resolved to give a course of scientific lectures of the very highest import and value within the power of American genius and culture to afford.

It is a very common, but I think a very undeserved reproach, that New York is so intent on money making, or on pleasure, that it has no time, no thought, and no means to give to the advancement of science.

On the contrary, I believe that if a project were to-day fairly presented to the rich men, and the public spirited men (who are not always the rich men) of New York, and if such a plan were to seem to them feasible and judicious, a million dollars would be freely bestowed, if necessary, for the achievement of the purpose therein indicated.

The Institute resolved to test, so far as it might, the justice of the reproach commonly made that this city is given up wholly to trade and money getting, and would give no thought to any more elevated or abstract purposes.

We resolved to give the best course of lectures on science, choosing that man whom we supposed to be best qualified to illustrate each important branch or department of natural science, in its present fullest development, and with the very latest discoveries which have enlarged its area.

This plan was matured, submitted to the Institute, approved by it, and the lecturers called not only from all parts of our country, but from the British provinces adjacent, where, I rejoice to say, that some of the very ablest of those who cultivate chemistry and geology, not merely as a practice but as a true science, were found.

This lecture to night is the last of the course. That course, we rejoice to say, has been sustained by the unanimous approval of the press, and by the presence here of very large and intelligent audiences, sometimes in spite of very discouraging weather.

We have seen and proved that science, even abstract science, has charms for a very large portion of this community; and we shall be encouraged.

While we did not expect to make money, and shall never make money by a course of this kind; while we shall expect to spend money in every such course, we shall be encouraged by the approval of judicious men given to this course, to make other, and if possible better arrangements for similar courses during the winters to come.

The lecture this evening is on **Modern Engineering,** and will be given by Prof. **William J. Me Alpine,** favorably known to the community as a very competent, practical, as well as educated engineer.

The New York *Tribune* of the twelfth of February, contained the following notice of the address and an abstract report thereof:

SCIENTIFIC LECTURES.

THE HON. WILLIAM J. McALPINE

ON MODERN ENGINEERING.

The twelfth and concluding scientific lecture before the American Institute was delivered on Wednesday evening, February 10th, at Steinway Hall, by Prof. **William J. McAlpine.**

Upon the platform were seated Horace Greeley, Admiral Farragut, Gen. CALLUM, Supt. of the U. S. Military Academy at West Point; Gen. H. G. Wright, commanding Sixth Army Corps; Gen. Tower, Engineer Corps U. S. A.; Gen. Q. A. GILLMORE, the capturer of Fort Pulaski, Fort Wagner, &c.; Horatio Allen, Civil Engineer, Novelty Works; Prof. Hosford, of Harvard ; Prof. Tillman, of New York, and others.

Horace Greeley, the President of the American Institute, made some introductory remarks, and at the conclusion the following resolutions were adopted:

In view of the entertainment and instruction afforded by this course of scientific lectures which has been closed this evening,

Resolved, That the thanks of the audience are hereby tendered to the American Institute and to the scientific gentlemen for the highly instructive entertainments thus provided.

Resolved, That the American Institute be requested to have this course of lectures published in book form.

MODERN ENGINEERING.

By Wm. J. McAlpine.

The subject of my address this evening has so wide a range and involves the consideration of so many branches of art and science, that I have been compelled to condense my remarks, and also to omit much of an interesting character to bring my address within the limit of the hour.

It cannot have failed to have attracted the attention of such audiences as have attended these lectures, that a marked characteristic of this age, is the wonderful rapidity with which discoveries in every range of art and science have succeeded each other. These are confined to no one branch of human knowledge, but apply equally to all pursuits of study. They now succeed each other like November meteors—dazzling in their brilliancy, so frequent, and spread so far over the arch of heaven as not to be even counted, far less comprehended.

The eminent scientists who have lectured before you have each been profound students in their own lines of thought, and almost they only know of, or at least understand, the discoveries in their own courses of study.

Our Creator has given us great mental powers, but to no one person sufficient capacity to grasp all knowledge.

When we have listened to the wonderful revelations of minute organism, as developed by the *microscope,* and find there the perfection of beauty and mechanism — or when, through the *telescope*, we learn of the constitution and government of those great but far distant heavenly bodies, and find there the same perfection of beauty and order; or when the *spectroscope, photometer* and *barometer* tell of the constituents of matter around us; or when an essay on the simple *tea-kettle* informs us of the practical application of knowledge to one of the most useful and powerful of the agents of modern progress, *then* we realize how impossible it is for one mind, however capacious, to grasp even a tithe of the discoveries which are daily being made.

My subject **(Modern Engineering)** requires a comparison of the past with the present. *Then* discoveries were of rare occurrence, and still more rarely applied to the useful purposes of life — *now* they are not only very frequent, but are immediately applied to the safety, comfort and convenience of man. The natural mental capacity of man has not increased since those earlier days, and therefore there must be some other explanation of its present changed condition.

An enthusiast, like Dr. Cummings, reasons from it, that the millenium is approaching, and another, that intercourse with the immaterial world is at hand—but the subject is too profound for our finite minds, and similar to divine prophesy, " the event is necessary to its solution."

An idea attributed to Bacon is, that, as in all animate life, thought must be impregnated by thought, to produce any useful result.

In ages past, intercourse between man and man was limited. He lived and died without having traveled beyond the horizon seen from his birthplace. Learned men were confined to cloisters. They rarely met, and their reflections were only occasionally set down in manuscripts, the circulation of which was confined to a few readers.

Hence by this Baconian theory but few scientific discoveries could then be made, and these were but seldom applied to the useful purposes of life. This age, on the contrary, presents the opportunity for frequent meetings and comparisons of thought. The steamer with its ten days of confinement, produces intercourse between minds which otherwise would have never met. The* railway car, with its rapid motion, exciting thoughts in the dullest traveler, brings other minds in contact. A prolific press sends forth the thoughts of each writer, to encounter those of other minds engaged in the same, or some kindred pursuit. While the telegraph daily sends the report of one or more discoveries, to stimulate the minds of some of the millions whom it reaches, to the consideration of the same or some other corresponding line of thoughts.

In all of these communions, the cruder thoughts of each person are cast into the crucible with those of a thousand other minds, by which errors are eliminated and useful suggestions generated, and the grand discoveries to which I have alluded are produced.

The profession of Engineering is peculiarly the exponent of this modern development. Its definition is, " The acquisition of that species of knowledge whereby the great sources of power in nature are converted, adapted and applie'd for the use and convenience of man." [1]

Under this definition is embraced the Civil and Military Engineer, the Architect and Mechanician, the Closet Theorist and the Practical Workman. Nevertheless, there is a broad distinction between the one who designs and plans an elaborate machine, and him who, with no scientific knowledge, merely con_ structs it, and again with him who, with no requirement

1 This is the motto of the Institution of Civil Engineers of Great Britain, and is embodied in their certificates of membership.

of either mechanism or science, is merely employed to direct its move_ ment, and yet, in common conversation the term " Engineer " is indifferently applied to each.

I shall presently lay before you at greater length, the effect of the great discoveries and applications made by this profession upon modern progress, and in this place will merely name the Locomotive and its Railway, the Steam Engine and its applica. tions, the huge masses of metal and their manipulations, the workshops and their great tools, modern ordnance and armor, naval construction, telegraphy, bridges, canals, water supplies, harbors, etc.

The mere mention of these is sufficient to give you an idea of the broad field which is covered by my subject, and why, as stated at the beginning, I have been compelled to condense and omit so much.

Under these circumstances I have considered it better to direct my remarks to the most important branch of the profession (civil engineering), with such incidental allusions to the others as maybe necessary.

The term " modern " will require some comparisons with that of ancient engineering, and I will give very briefly a few of the leading points in the history of the profession so as to define the " modern age."

Ancient Engineering.

The history of **Highways** commenced with the bridle paths of the rude people who first tamed the wild animals, the introduction of carriages for the aged, sick and powerful, and culminating in the modern paved roads and railways;

That of the navigation of **Rivers,** large and small, from the days of rafts to the magnificent steamers of the present day;

Of artificial **Canals,** first for irrigation, and then their adaptation for transportation, beginning by copying the natural rivers, even to the inclined water and land planes, over which the vessels were carried, and after the thirteenth century with locks;

And in the history of those small vessels, with wooden frames, covered with osiers and hides, which first navigated the pacific inland seas, and next those which coasted the oceans, seeking a harbor each night, then the great show ships of Italy and Egypt, and finally the immense merchant navies of the present day.

Referring to Divine History we find that the first mechanician (an antediluvian) was " an instructor of every artificer in brass and iron," and that the first naval engineer constructed a vessel which has only once since been exceeded in size, and that the first architect built " a city and a tower," which became one of the seven wonders of the heathen world. We .find, also, the architect of the Tabernacle, who was " learned in all of the knowledge of the Egyptians," and him of the first Temple who was endowed by God with " wisdom and knowledge " beyond that of any other man, and him also of the second temple who was possessed of all the learning of the Chaldeans.

In profane history we find Hercules deified for draining the marshes of Thessaly ; and the first bridge builder, Semiramus, whom we are the more proud of classing in our profession as she was a woman, and who is also said to have tunneled the Euphrates, constructed canals and reservoirs for irrigation, and com, menced the walls and hanging gardens of Babylon. Of Phidias, the constructor of another of the seven wonders, who built the first water works of Athens, tunneling Mount Athos for two miles, with a passage of eight feet diameter; of

Archimides, the military engineer, who defended Syracuse so long by his science alone against the whole power of Rome ; and of Vitruvius, the anylist, by whose engineering rules we are yet governed.

But the early history of the profession has been best written in its monuments, extending from the days of Abraham to those of Constantine. In the great temples of Assyria, Egypt and India, and those of the Central and Southern American continent; of the long canals for transport or irrigation in China, India and Egypt; of the water-works, with their tunnels through mountains; aqueducts over valleys; immense reservoirs, and systems of pipes, and in the great military roads, bridges and sewers of the Romans.

These histories bring us down to the first centuries of the Christian era—the Augustan age of ancient engineering—after which civilization was overwhelmed by or lapsed into barbarism, and engineering was only practiced by a secret fraternity of Masons, " The Brothers of the Bridge."

Modern Engineering.

With the revival of civilization in the seventeenth century dates the commencement of modern engineering, though the term will be more particularly applied to the last hundred years.

This revival began in Italy, in the construction of canals for irrigation, and subsequently with those for transport with locks, which had not been used until the thirteenth century; in the investigation of the laws which govern the flow and pressure of water, and in the construction of great hydraulic works— bridges over rivers, harbors and docks, and the reclamation of lands under water.

The great canals of France, Holland and Great Britain, and the improvement of rivers; the thousands of acres of wet docks in England and France to overcome the inconvenience of the tidal wave, harbors and light-houses, show the progress of the profession for the next two centuries.

The last century has been characterized by the application of steam to water and land transport, to every variety of mechanical operations, to the product and manipulation of metals, to telegraphy, and to printing in its various improved forms.

Some of the most distinguished of the earlier of the modern engineers were recruited from other trades and professions, and were drawn into it from circumstances, or a natural inclination toward the study of the physical sciences.

With the continued advance of refined civilization, the demand for this service called for a higher degree of elementary education, until it has required from the modern engineer, not only the highest degree of knowledge in the physcial sciences, but also long practical experience and sound judgment in the application of such knowledge.

During this period the profession—as in all others—has suffered somewhat in the public estimation by pretenders, quacks and charlatans.

The wide dissemination of knowledge among our American people has now reached a point which enables the claims and merits of an engineer to be fairly judged, and henceforth such pretenders will be employed only in schemes of doubtful expediency, or by those who are themselves but little acquainted with the ordinary principles of science.

The ordeal of criticism by our daily and other periodical journals serves, not only to expose such pretentious claims, but also to restrain the eccentricities of genius, and now compels the engineer to the enunciation of sound theoretical as well as purely practical plans.

The Locomotive.

I have referred to the effect of the great discoveries and appliances of engineering upon modern progress. The first of these of which I shall speak is the locomotive, a machine of purely modern invention.

When I first entered the profession, but little more than forty years ago, it had not been successfully used anywhere, and was almost wholly unknown in this country.

At the beginning of this century, a rude machine of this kind was invented by our countryman, Oliver Evans, and a few years later was reinvented in England, and after the trial of many modifications and expedients, during the succeeding twenty-five years, the celebrated trial of locomotives was had at Liverpool, in 1829.

Stephenson won the prize at this trial with the Rocket (which is now kept on exhibition at the Kensington Museum), an engine which weighed but four and a quarter tons, ran fourteen miles an hour, and hauled a gross load of seventeen tons.

To exhibit the progressive changes in the locomotive, the maximum speed attained at different periods will be given. In 1834 it was twenty miles an hour ; in 1839 it was thirty-five miles; in 1847 it was sixty miles, and since that time a speed of one hundred miles an hour has been attained.

The first locomotive in the United States was driven by horse power, in 1829, and attained a speed of ten miles an hour, and was designed by Mr. Detmold of New York, who the next year built a steam locomotive for the Charleston, South Carolina railway.

In 1829, Horatio Allen, of New York, brought over two locomotives from England for the Carbondale railway.

In 1830, Peter Cooper placed a small one on the Baltimore railway, and in 1831, John B. Jervis designed and placed two locomotive engines upon the Albany railway, one of which was built in England and one at the West Point foundry.

There are now some fifteen thousand locomotives on our American railways, and on one line in England there are about three thousand.

The usual weight of the locomotive is now thirty tons, but there are a great many in use of forty, and a few of fifty tons. M. Petiet has placed twenty-five locomotives df sixty-nine tons weight upon the northern railway of France to run the London express passenger trains between Paris and Calais. These are mounted on twelve drivers and carry their own wood and water.

It was *once* considered that curves of less than half a mile radius, or grades of more than fifty feet per mile were inadmissible. *Now* curves of five hundred feet radius, and grades of one hundred feet per mile are common.

The temporary railway over Mount Cenis has long grades of four hundred and forty feet per mile, over which all of its traffic is conducted by locomotives grasping a central rail.

Some years ago there was also a temporary track on the

Baltimore railway of five hundred and twenty-eight feet per mile, up which the locomotives daily hauled twice their own weight.

Forty years ago Mr. Allen had to mount the foot-board of the first locomotive and run it himself. Not a mechanic in the employ of the railway company dared to let loose this monster. *Now,* fifteen thousand of them are daily whirling over forty thousand miles of railway in this country alone, and nearly twice as many in the rest of the world.

To-day, locomotives are crossing the summit of the Rocky Mountains and of the Sierra Nevada—more than eight thousand feet above the level of the sea—and pass over more than three thousand miles of continuous railway from the Atlantic to the Pacific Ocean.[2]

What changes have this *one* engine of the profession brought about in the condition of society in this country ? From the days of Noah until those of the locomotive, civilized population all over the globe was confined to the rivers, lakes and borders of the oceans, or a day or two's ride into the interior.

The mariner's compass carried this population across the Atlantic, where, following the same law, our settlements were confined to the vicinity of these water courses.

As soon as the locomotive was inaugurated, our railways were pushed forward into the interior of those immense fertile districts of the West, and they were populated with unexampled rapidity, and then began that era of prosperity which has raised our country to its eminence among the nations.

This era has been unlike any which has preceded it in the world's history.* An avalanche of people upon a wilderness almost in a day. Not like those northern hordes upon the civilized plains of Europe and Asia to lay waste and destroy, but a migration of the highest degree of civilization upon barbarism, to build up and create.

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2 See Appendix A for a statement of the railways of the world.

Without the locomotive these fertile lands, their wealth of minerals and forests, their great cities, their industrious, wealth-producing population—yea, more than one-half of the population and sources of our prosperity would have remained undeveloped for ages, perhaps forever.

Changes like these of our own country are now in operation all over the world, and railways have been built or projected even through the most barbarous regions.

But there are too many of these engines of the profession to allow me to dwell long upon any one of them.

The second one to which I will refer is the application of steam to the propulsion of vessels. This has covered every ocean, lake and navigable river with fast moving, deeply-laden vessels, conveying the peoples and products of different climes and nations to others, and enhancing the comfort, convenience and profit of all.

You will remember that all this has been accomplished during the nineteenth century, and that the chief development has been made in but little more than thirty years.

Twenty years ago a voyage of twenty days across the Atlantic was called a quick passage; now it is made in eight, and .will soon be made in six days.

Indeed, the question of speed on either land or water may now be determined by the public. Almost whatever speed it is willing to pay for, the engineer is ready to furnish.

The construction of railways and steam vessels has called into requisition the highest engineering skill that the world has ever known. Bridges of extraordinary span and strength, vessels of immense burden, machinery of great power, massiveness, and accurate workmanship. The Britannia and Niagara bridges are but types of thousands of similar structures all over the world.

The Great Eastern steamship of twenty-two thousand and five hundred tons is premature by only a few years, for those of six thousand, seven thousand and even nine thousand tons are now built. And the enormous engines and ponderous, masses of metal required by them, have taxed the inventive power of the mechanicians.

Canals.

The great canals executed in our day form an important feature in this progress. I shall endeavor to illustrate my subject, as far as possible, by American examples, and will therefore next refer to the Erie Canal; and the more so, because in conversation with many, otherwise well informed persons, I find that they do not fully appreciate the importance of this great work upon nearly all of the interests of this city, of this State, and of the nation itself.

With many persons there is an idea that the railway has superseded the canal, and that the former now performs the chief part of the traffic of the country. While the latter is true in regard to interior short lines of trade, it is a serious error in reference to the great transport between the agricultural West and the Atlantic.

It is difficult to realize the importance of the Erie Canal, which now conveys one-fourth of the exports of the vast interior region of our country and as much of it, during its six months of uninterrupted navigation, as all of the trunk railways together during the same time.

Every canal boat which comes to tide-water with an average cargo contains more than the average tonnage of a railroad freight train.

In the busy canal season, more than one hundred and fifty such boats come daily to tide-water, and none of the trunk railroads exceed fifty freight trains per day.

Such a canal traffic would require the arrival of more than forty miles of railroad cars; and there is neither room nor conveniences for discharging one-fourth as many.

The slow, plodding canal boat attracts no attention, while the bustle, noise and whirl of a freight train creates a sensation in every village through which it passes.

The locks on the canals act as regulators of the boats, which are kept separated by the distance which they would move during one lockage; and hence while the canal business proceeds methodically it gives no adequate idea to a casual observer of its great volume. Nor is this appreciated until some stoppage occurs, and then a delay of twenty-four hours will accumulate hundreds of boats ; the cargoes of which would fill the track of the New York Central railway half way to New York.

Imagine, the effect of a catastrophe which would interrupt the navigation of the canals for one season.

All of the New York railways combined could not transport one-half of the canal tonnage; the entire capacity of all of the railways to the seaboard in their present condition would be insufficient to convey it.

Half the merchants of New York, connected directly or indirectly with this canal traffic, would be bankrupted, and their rivals in Portland, Boston, Philadelphia and Baltimore would be correspondingly benefited.

The four thousand canal boats, of an aggregate of a million of tons, moving five millions of tons of cargo per annum, exceeds the tonnage of all the vessels engaged in the foreign commerce of this city, even before the war.

In another place I have alluded to the great trade of the West, which will soon exceed the capacity of even this enlarged canal, and require it to be again enlarged for vessels of a thousand tons, or three times those now in use.

A few days since the State Engineer informed me that there had been used, up to this time, more than two and a half millions of tons of stone in its works of masonry, and more than seventy-five millions of tons of earth and rock in the construction of its channel—more excavation than will be used in the building of the two thousand miles of the Pacific Railway.[3]

City "Water Works.

The works for the public supply of water to all of our great, and to many of our smaller cities and villages, deserve mention.

There is hardly a town, especially in the northern part of this country, which has not a public water supply, and the engineering works of the most of them have been skillfully executed.

But there is no work of this kind in the world which will compare in engineering merit with the Croton, in the designs for its structures, and their construction in the most skillful and durable manner, without unnecessary expenditure, and solely for utility, and at a cost so moderate as to astonish the profession.[4]

3 See Appendix for a statement of the dimensions, etc., of the canals of the world, also of the cost of transport by land and water.

4 This remark applies only to the original construction.

Bridges.

Our American examples of bridges are almost without number, embracing those of nearly every material and form, and many of them of huge proportions. Among the most noted of these are the Niagara and Cincinnati, of wire, suspension, by Roebling; the iron trusses over the Ohio, by Fink, and the Mississippi, by

Clark; the stone arch near Washington, by Meigs; the Havre de Grace, of wood, by Parker; the cast iron arched bridge at Philadelphia, by Kneass; the Victoria (Montreal) bridge, by Stephenson (a duplicate of the Britannia iron girder bridge), with hundreds of others equally deserving of mention.[5]

Submarine Works.

The submarine works executed by our American engineers have required a degree of science and skill at least equal to that demanded for any European work.

The most important of these are the founding of the piers of the Potomac and Croton Aqueducts ; of the Havre de Grace and Harlem bridges; and the foundations of the United States' Graving Dock at Brooklyn.[6] A brief description of the latter will serve to explain the engineering difficulties which were also encountered in the others.

This structure weighs seventy-five thousand tons, and is sustained on a quicksand of more than a hundred feet

5 See Appendix for dimensions, etc., Of many of the large bridges.

6 Since the above was written, the foundations of the tow piers of the East River Bridge, and those for the St. Louis Bridge have been completed, and are the most stupendous and successful illustrations of the pneumatic system that can be found in the world.

depth. The foundation had to be placed at a level forty feet below that of the sea, and rendered perfectly unyielding. The sea water had to be shut out by massive coffer-dams, which were twice undermined by the pressure of the water, and the land portions of these dams — subjected to the pressure of the liquid quicksand, of nearly twice the weight of water — repeatedly broke the chain cables by which they were secured (these cables being the best bowers by which our largest men-of-war ride in the heaviest storms). Fresh water springs, with a head far greater than that from the sea, again and again undermined the piles (driven nearly forty feet) and forced up large areas of the foundation, by their hydrostatic pressure, although heavily loaded. The super-structure of the finest cut granite, in which the slightest yielding would have been perceptible, stands to-day as firm as if founded on solid rock [7]

The Harlem Bridge has been mentioned because of the novel construction of its piers, and a growing opinion on the part of American engineers that this system of founding piers in difficult places will, in this country as in Europe, supersede those heretofore used.

These piers are composed of large cast-iron columns, six feet in diameter, fifty feet long, and fifty tons weight each. These enormous piles were driven twenty-five feet deep into the gravel and rocky bed of the river, by the modern invention of the pneumatic process, by which, with a six-horse engine, an air-pump, and a dozen men, these huge masses of iron were handled with certainty and ease.

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7 See Appendix for details of the foundations of the U.S. Graving Dock, at the Brooklyn Navy Yard.

I have stood on the platform and with a turn of my wrist sent this fifty tons plunging downward with almost frightful velocity, and then arrested it within the fraction of an inch of any desired depth.[8]

The eastern terminus of the Pacific Railway at Omaha is now being connected with the railways on the east side of the Missouri by a bridge, the piers of which will be of cast-iron columns of eight feet diameter, driven eighty feet below the bed of the river by the same process.

Machines and Tools.

The civil engineer, however, has been enabled to accomplish some of his most stupendous undertakings through the instrumentality of the large masses of metal and the workmanship thereon, and by means of the great tools and engines with which he has been furnished by the skill and genius of the mechanical engineer.

A mass of bronze or of iron of a ton weight, of specific form and workmanship, was almost, if not quite, unknown before the Christian era. Now we have those in cast-iron of from one hundred to one hundred and fifty tons, and, in common use, of from forty to sixty tons; in wrought iron of thirty to forty tons, and in steel or bronze of twenty-five tons, cast in any desired form, and planed, turned or bored with an accuracy and finish equal to that of the works of a delicate Geneva watch.

Bessamer has an anvil-block of cast-iron, made at one casting, of more than one hundred tons, and Krupp has another of one hundred and fifty. But neither of these required the skill which produced the bed-plate of the Adriatic (Collin's

8 See Appendix for notes on pneumatic foundations

steamer) of sixty-five tons, cast at the Novelty Works ten years ago, or those frequently made at other work shops. The casting of the former could be protracted through two days, the latter had to be cast many hours, or they would have been ruined.

Ten years ago Mr. Allen cast and bored a steam cylinder of sixty-four square feet area in which he gave a dinner party and seated twenty-four persons.

I have recently examined some of the largest " tools," as they are technically called, in the great workshops of the country, and have received from the proprietors statements of their dimensions and capabilities.

Although my business requires me to study this part of the profession, I confess that I cannot keep up with the constantly increasing proportions of these Leviathan tools.

Two years ago I examined the largest lathe in England (Forrester's at Liverpool), which swings twenty-two feet and will take in a shaft of forty-five feet length.

Six months ago I saw one at Corliss's, at Providence, which swings thirty feet, and will take, in a shaft of fifty feet. In the former was turned off the main shaft of the Great Eastern, which weighs twenty-two tons.

The shafts of the Bristol and Providence (Sound steamers) also weigh twenty-two tons, and those of the China steamers Japan and Great Republic weigh thirty-three and thirty-four tons, and they were turned off in American lathes.

Corliss has recently cast pulley fly-wheels of thirty feet diameter and nine feet face, weighing fifty-six tons, and turned them off in his large lathe, and he is now finishing off a spur-wheel of the same diameter, weighing forty-five tons, and cutting on the face by machinery, cogs of twenty-four inches face and five and a half inches pitch.

During the war he turned off twenty-five brass turret plates for our Monitors, of twenty-five and a half feet diameter—having at that time the only lathe in this or any other country in which they could be turned. He has also a planer which planes iron of fifty feet length, and others of ten feet height, or width.

At the Boston Navy Yard is a machine, just set up, which will plane a piece of iron sixteen feet long, eighteen feet wide, or fourteen feet high.

At the Morgan Works, New York, John Roach and Sons, there is one of these machines that will plane twenty-seven feet long, fourteen feet wide, or twelve feet high, and a slotting machine that will cut a face of eight feet diameter and seven feet high. There is also a boring mill at this shop which will finish off a cylinder of one hundred and thirty inches diameter and eighteen feet stroke. These planers and slotters cut off shavings in iron of two and a half inches width and nearly a quarter thick, and some of them are arranged with several of these cutters all working at the same time.

The rolling of the enormous plates for the iron-clad vessels of war requires, also, tools of immense size and power.

But time would fail me to describe the power and majesty of these perfect, though ponderous tools.

They furnish to the modern engineer thunderbolts more powerful than those forged for Jupiter. But they are used to build up and create—not to destroy.

Military Engineering.

Not long since I witnessed the complete perforation of a wrought-iron shield for an embrasure, of Fort Delaware, made of two plates measuring together fifteen inches thickness, by a cannon shot of twelve inches diameter and six hundred and twenty-four pounds weight, fired from a constructive distance of five hundred yards, and a distinguished officer remarked: " Gen. Rodman has in reserve his fifteen and twenty inch guns, but American engineers and mechanicians will soon furnish us with shields strong enough to resist even these enormous projectiles."

The active force of the powder on the ball was forty thousand pounds per square inch—equal to twenty-two hundred and fifty tons—giving it an initial velocity of twelve hundred feet per second, or eight hundred miles an hour.

The weight of spherical cannon shot are as the cubes of their diameters, and therefore one of twenty inches is five times as heavy as one of twelve inches.

The " work " of a cannon shot is in direct proportion to its weight and the square of its velocity, and the effect of rifling the gun is to largely increase the effect of the shot and its range. The largest American gun weighs fifty-eight tons, and throws a ball of one thousand and seventy-two pounds. Krupps' great steel rifled gun of fourteen inches bore, weighs fifty tons and would throw an elongated ball of a thousand pounds. It has been fired but twice.

The largest English gun that has been tried, with a moderate degree of satisfaction, is the thirteen and three-tenths inch Armstrong rifle, weighing twenty-six tons and throws a ball of six hundred and ten pounds; but these guns have all burst; and even the twelve inch English gun is considered as yet an experiment.

The twelve inch Rodman rifle weighs twenty-six tons and throws a solid elongated shot of six hundred and thirty pounds, and even a steel shot of six hundred and eighty-four pounds.

The " Swamp Angel," used at the siege of Charleston, weighed eighteen and a quarter tons. It was an eight inch Parrott rifle, and threw shot of one hundred and fifty pounds into Charleston from a distance of five and a half miles.

The foundation of the "Swamp Angel" was a novel one. It actually rested on fluid mud sixteen feet deep; but the mud was confined in a square box of forty feet, made of sheet piles, driven into the sand below and made "mud tight."

The platform of the gun (including the gun) weighed twelve tons, and was a mud-tight piston, fitting the box tightly.

The great ancient rival of the "Swamp Angel " was the " Mons. Meg," now at Edinburgh Castle. It is thirteen and a half feet long and twenty inches bore, with a powder chamber of nine and three-quarter inches diameter, and the charge was " a peck of powder." The balls used were of stone, eighteen and a half inches in diameter.

It was used at the siege of Dunbarton in 1489, and was injured in firing a salute in 1682. There used to be a quaint inscription upon it, about in these words :

" Load me well, and sponge me clean ;
And I'll drop you a shot at Calais Green,"

a distance of sixteen miles.

There was some poetic license used by this ancient rhymster. for one of our distinguished engineer officers informs me that with the most liberal allowance in his calculations, and with the advantage of ricochet on water, this gun could not possibly have had a range exceeding one and a half miles.[9]

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9 It should not weaken confidence in these calculations when I add that they were made by the gallant officer who had the direction and the firing Of "Mons. Meg's" great rival, the "Swamp Angel."

The capture of Fort Pulaski, near Savannah, affords a good illustration of the unerring certainty of the calculations of the effect of ordnance by modern military engineers.

The breaching batteries had to be placed at a mile from the fort. The engineer (who is also a member of our civil society), prepared his plans before leaving Washington, complete in every particular.

I cannot refrain from using the General's own words, although stated at a social meeting, they have so thoroughly the ring of the true metal of the engineer, who, with science, experience and judgment, *knows* the result of his operations *before* he begins them.

He said: "The capture of that work had been calculated and worked out on paper, with an almost absolute certainty of the preëstimated results, and I had almost as much confidence in my ability to breach the walls, as if I had gone to work on them with masons, hammers and chisels."

Whitelaw Reid, in his "Ohio in the War," says:

" On the evening of April 9, 1862, Gen. Gillmore issued his order for the bombardment. It was remarkable for the precision with which every detail was given. The directions for the breaching batteries will illustrate." [Here follows Gen. Gillmore' s order.]

Mr. Reid continues : " These instructions, with few exceptions, were adhered to throughout. For their striking illustration of the unerring as well as preëstimated results of applied science, engineers and artillerists will hold them not among the least remarkable features of the seige.

" They were addressed to raw volunteer infantry, absolutely ignorant of artillery practice until the siege commenced, and taught what little they knew about serving the guns in the intervals of leisure from dragging them over the beach into battery," &c., &c.

Construction Corps U. S. Army.

A modest pamphlet of forty pages was published at the end of the late war. It is the Report of Gen. D. C. McCallum, on Military Railways.

By a summary of their operations it appears that at one time there was a force of twenty-four thousand nine hundred and sixty-four men employed on these railways, two thousand one hundred miles of railway were operated with four hundred and nineteen locomotives and six thousand three hundred and thirty cars, and there was built and rebuilt six hundred and forty-one miles of railway, including twenty-six miles of bridges, and the whole expenditure of the department, after deducting the materials sold at the conclusion of the war, was a little under thirty millions of dollars.

When Gen. Grant advanced from Washington, on' his final campaign, the Rappahannock bridge, six hundred and twenty-five feet long, and thirty-five feet high, was rebuilt in forty hours, including the furnishing of all of the timber from more than fifty miles distance, and the Potomac bridge, near Acquia Creek, four hundred and fourteen feet long, and eighty-two feet high, was built in the same number of hours.

Fourteen miles of the railway was rebuilt in eight days, and was used for only one week, to convey eight thousand wounded men of both armies from the battle fields of the Wilderness and Chancellorsville.

On the evacuation of Richmond by Gen. Lee, the commander of the confederate army the railway was relaid, and put in operation as rapidly as the troops marched.

The cuts had been filled up with rocks, logs, brush and telegraph wires, presenting unusual difficulties, all of which had to be removed, the ties cut from growing trees, small bridges and culverts made, iron rails furnished and laid, and all of the sidings, water tanks, etc., renewed for a distance of nearly sixty miles, all of which was completed and ready for the locomotives at an average rate of a mile an hour. The order was that the railway must be completed to headquarters every night. Frequently the construction corps advanced, with a completed railway, faster than those who were employed in laying down the telegraph lines.

In one case a bridge near Petersburgh, thirteen hundred feet long, and from fifteen to thirty-five feet high, was built from trees which were standing when the bridge was commenced, and it was completed in the seventy working hours of three days.[10]

At the West, on Gen. Sherman's march from Chattanooga to Atlanta, in May 1864, the railway was constructed and " kept pace with the army." The Chattahoochie Bridge, seven hundred feet long, and ninety-two feet high, was built in four and a half days.

In October of that year the confederate Gen. Hood passed around Sherman's army, and destroyed thirty-five and a half miles of the railway, and four hundred and fifty-five feet length of bridging. In thirteen days after he had retreated, the line was restored, and the trains run regularly. In one case twenty-five miles of track and two hundred and thirty feet of bridging in one stretch, at Tunnel Hill, were reconstructed in seven and a half days.

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10 This work was done under the personal direction and superintendence of the author's brother.

In February, 1865, Gen. Forrest destroyed a long line of this railway, and in thirty days it was reconstructed, including two thousand two hundred feet of bridging.

Gen. McCallum says: " Had any failure taken place, either in keeping these lines in repair, or in operating them, Gen. Sherman's campaign, instead of proving, as it did, a great success, would have resulted in disaster and defeat."

Gen. Cullum told me that on the march to Atlanta some confederate prisoners (old graduates of the U. S. Military Academy) expressed their astonishment at the wonderful rapidity with which the railways were reproduced. They said, "while bridges were yet burning your men had often commenced their reconstruction, and before the roar of the cannon were out of hearing, your railway trains were crossing these bridges."

The reply was that Gen. Sherman had duplicate railroad bridges always ready.

But, said another, " Your progress will be arrested at Tunnel Hill, for we have blown up the tunnel."

" I doubt it, said a companion, " for the Federals have also probably a duplicate tunnel on hand."

Steam to Agriculture.

The application of steam to the various purposes of manufacture, is worthy of a lecture by itself, and one can only realize its extent when passing through the numberless workshops engaged in such manufacture in our eastern cities and villages.

I shall say no more on this subject at this time, except to call your attention to the recent successful movements, to apply steam power to agriculture. We have seen the resulting benefits from the introduction of the mowing machine, cultivator and reaper, worked by horse power, but we are soon to witness all of these as well as plowing done by steam power.

The effect of this will be to bring thrice the number of acres at the West into use, and of increasing the crops more than three times as much as the present product, and soon render the great West the chief food-producing region of the world.[11]

Telegraphy.

Telegraphy may, with propriety, be considered one of the branches of engineering, and is peculiarly of modern development.

A clever writer says that the telegraph may be read by each of the five senses. On land lines each signal is made by suspending the flow of the electric current, for two different intervals of times, called "dots and dashes"—the use of which, in different orders, constitutes the alphabet of the telegraph. When these are printed, they are read by "sight," but ordinarily the operator reads them by "sound," as easily as the musician reads the letters of the scale by the same sense. If the operator has no instrument, he will grasp the wire in his hands, and read the signals by " feeling" the intermissions of the flow of the electric current. In like manner, by placing the wire across

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11 The whole cereal product of Europe in 1867 was a little short of five thousand millions Imperial bushels, and that of the United States in 1868 was fourteen hundred millions or nearly one-third. The cereal product of Russia was about the same as that of the United States.

In an address to the merchants of New York, in 1873, the author estimated that the cereal products of the Western states would be doubled in ten years, equal to three thousand millions of bushels. (See Appendix, D.)

his tongue he can "taste" the same intermission (but this is a dangerous experiment). And it is said that the electricity can be made to dissolve a chemical and produce a pugnent odor in the telegraphic alphabet, which can be read by " smelling," but for this I do not vouch.

I believe that the method of signaling through the Atlantic Cable is known in detail to but few persons.

The operation is exactly reversed from that on the land lines.

The gutta percha covering of the copper wires, under the pressure of a great depth of water, becomes an absorbent of the electricity which is being sent through them to the extent of ninety per cent.

The first portion of the electric wave of ten per cent, crosses the ocean (seventeen hundred miles) in two seconds, and it would be followed by a succession of waves from the restoration of that portion of the electricity which has been absorbed by the gutta percha, in impulses, and the signal would be repeated like echoes, and produce not only confusion, but great delay.

To remedy this, Professor Varley introduced a key, which sends alternate currents, positive and negative, at such intervals as to allow the first wave of ten per cent, to pass forward, and then that portion absorbed by the covering is neutralized by ninety per cent, of the next wave of the opposite kind of electricity, and the- cable is cleared for the transmission of a second pair of these opposite currents.

The battery used is a very small one (three of Daniels's cups), and the signal being only ten per cent, of this small current, is powerless to move any of the instruments which are used on the land lines of telegraphs.

The instrument used consists of a minute polarized needle, suspended on a single strand of a spider's web, or one from the silk worm. In the middle of this minute needle is placed an almost microscopic mirror, which reflects a single ray of light from a powerful lamp. The two kinds of the electric currents deflect this needle alternately to the right and left for a space of time corresponding to that occupied in the signal on the land line, the same kind of alphabet being used in both cases.

The receiver (not operator) sits in a dark room, and the small mirror reflects the rays of light upon a piece of white paper before him, on which a black line is drawn, to the right and left of which the light is alternately reflected.

The receiver reads these signals by "sight," and transmits them to another person, placed outside of the dark room, by means of an ordinary instrument.

A short time since, Gen. Reynolds told me that he had sent a message, without either a wire or cable, ninety-two miles, across an arm of Lake Superior, by means of the Heliotrope or sun mirror, and on the return of his messenger (who had been sent with a written copy), he found that the Heliotrope message had been received, understood, and obeyed.

He had two assistants, who had been telegraphic operators, who had for the whole summer been amusing themselves in talking to each other with these instruments, although they were stationed ten, twenty or thirty miles apart.

When the Confederate Gen. Morgan made his great raid through Indiana and Ohio, he captured one of my telegraph operators, and compelled him to send a message in Gen. Lew. Wallace's name to Cincinnati, asking how many regular troops were in that city.

Morgan was also an operator and read by "sound," and therefore the captured operator did not dare to intimate that he was under duress, and could only venture to add an extra initial to his own signature.

The receiving operator at Cincinnati knew that Morgan was in that neighborhood, and suspecting, from the extra initial letter, that all was not right, replied, greatly exaggerating the force of regulars in the city; and the consequence was that Morgan changed his route to a circuit of twenty miles beyond the city, and thus saved it from a sack, and the probable loss of millions of dollars.

Ancient and Modern Engineering Compared.

The consideration of the subject requires me to contrast modern engineering with that of former times.

In the early ages the duties of the architect and engineer were combined, and we must refer to the works executed by the former for the practical examples for the profession.

One of the results of a high degree of civilization is the division of labor, by which a greater perfection is attained by those who devote themselves to one pursuit, than when their studies are directed to several different, even though they are analogous ones. It is this condition of society which has, in modern times, separated these professions.

As now understood, the former (the architects) are men of educated taste, who apply themselves almost exclusively to the designing of public and private buildings, while the latter (the civil engineers) are men of scientific mechanism, who are chiefly engaged in designing and constructing roads, railways, canals, water works, and their necessary mechanical adjuncts.

In a comprehensive sense, engineering also includes architecture, as a mechanical art, in distinction to it, as a fine art.

While the duties of each run somewhat into the field of study of the other, yet they are, and ought in practice to be separated, so as to give the highest degree of perfection to each.

The engineer is required to follow the exact rules of mathematics, the stern deductions from science, and the rigid laws of mechanism, all of which unfit him for the higher flights of taste and imagination, which distinguish the architect; while the consideration of these laws, and the details of construction dwarf the genius and taste of the architect.

The works which the engineers in both ancient and modern times have been called upon to design and execute, are confined to those which are required in a highly cultivated condition of society, and where the accumulations of the profits of past industry furnish the pecuniary means.

To some extent, therefore, their works belong to the luxuries of the age ; nevertheless it may be said of those of modern times that they are in an eminent degree those which are of the highest practical value to society.

The wealth and prosperity of any country depends upon the skill and amount of its labor, usefully applied. The dense population of semi-barbarous nations, like China, lack the skill and application. The frozen regions prevent, and the torrid ones destroy, the inclination to labor.

It is in the northern temperate zones that we find the greatest amount of labor and skill in its application, and through this belt shall we find our chief examples of engineering.[12]

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12 "There is no energy without frost, and no poctry without summer."-CONKLING.

One of the remarkable physical features of the North American Continent is the existence of a plateau nearly in its geographical center, on the north line of Minnesota, from which navigable streams flow north, east and west into the three great oceans.

The territory lying to the south and east of this remarkable plateau, in the salubrity of its climate, in the fertility of its soil, in its varied productions, and in its extent and ready access to the great markets of the world, combines advantages superior to any other portion of the globe.

Its discovery, settlement and development have followed each other so rapidly, that its history must be written annually, to keep pace with its progress, or to form a basis of an adequate estimate of its future importance and influence upon the trade and commerce of the world.

Seventy years ago this region contained only scattered forts and trading posts, *now* it has one-third of the population of the nation.

The world has never before witnessed such vast movements of "peoples" as have in this century flowed westward, and subsided upon this area. The migrations of the earlier ages were of savage hordes upon civilization—to lay waste and barbarize. This has been a migration of industry, intellect and wealth, to subdue a wilderness by the axe and plough.

It is the peculiar duty of the engineer to instruct and direct labor; and his value in his calling depends greatly upon his knowledge of, and ability to instruct in, the best methods of applying either skilled or unskilled labor.

The works of the ancients are often referred to, as excelling in magnitude, accuracy of workmanship, and beauty of design those of modern times.

This view is, in part at least, quite erroneous.

The engineers of those days were employed by rich and powerful patrons, who furnished them numerous, though generally unskilled, laborers; materials without regard to cost, and money without stint.

Their works bear evidence of these conditions, and were chiefly confined to monuments of useless victories, or constructions in compliance with the whim or caprice of the monarch, or in deference to their idolatrous worship.

Yet there are exceptions. The transport canals of Egypt and China, those for irrigation in India and Assyria, the waterworks all over the East, the vast military roads which radiated from the Imperial city and extended to the extremity of the Empire,[13] the bridges over rivers, and the ports and harbors of the inland seas, all bear evidence that these engineers were

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13 "All of the cities of the empire(which then had three hundred millions of people under its rule) were connected with each other and with the capital by the public highways which, issuing from the Forum of Rome, pervaded the provinces and were terminated only by the frontiers of the Empire." If we carefully trace the distance from the wall of Antoninus, through York, London, over the English Channel, and through Rheims, Lyons and Milan to Rome, and thence across the Adriatic through Bvzantium, Tarsus, Antoch and Tyre to JERUSALEM, there was in all a distance of 4,080 Roman (Or 3,740 English) miles, of which but 85 were by water.

Nor was the communication of the Roman empire less free and open by sea than it was by land. "From Ostia (a port sixteen miles from Rome) vessels, with a favorable breeze, were frequently carried to the gates of Hercules in seven days, and to Alexandria, Egypt, in ten."-GIBBON.
I have seen on the Danube, the remains of a highway, constructed by Trajan in the second century, forming a shelf for many miles, cut out of the face of the rock cliffs before gunpowder was known.

often called upon to plan and execute works designed for utilitarian purposes.

While the great canals of China and those of Egypt were but imitations of the natural water-courses, without locks, yet many of the other works referred to, and especially those constructed by the Roman engineers, are fine examples of professional practice.

Large Monoliths.

In alluding to the great works executed by the ancient architects, mention must be made of the Temple of Baalbec, wherein are found the larg6st stones (save one) in any building in the world.

Three of these measure sixty-eight, sixty-four and a quarter, and sixty-two feet in length, fifteen feet in height, and from the fourth corresponding stone yet in the quarry, but broken, the widths, or depths into the wall, are also fifteen feet.

Bayard Taylor estimates that these stones are eight thousand tons weight, but by the above measurement the largest one weighs but twelve hundred and seventy-five tons.

The quarry from which these stone were taken was within a mile of the Temple.

The Monoliths of Egypt are from two to three hundred tons weight, and a few of seven hundred tons. The Obelisk

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A modern McAdam turn pike on the opposite side of the river now supplies the place of this old Roman road. There are also at the same place near Turkey, the remains of a canal, larger than the Erie, built by the same Roman Emperor, and recently called upon to make the examination for a water channel over the same route as the ancient canal. Such highways and bridges are found wherever that great nation extended its sway.

of Luxor, now in Paris, is of Seven granite, and weighs two hundred and fifty tons.[14] The covering of a tomb at Ravenna is a single stone of thirty-four feet diameter and four feet thick, and weighed when quarried a thousand tons.

The " goodly stones " of the Temple, to which the Disciples called our Saviour's attention, according to Josephus, were of the " whitest marble, upward of sixty-seven feet long, seven feet high and nine feet broad," and therefore must have weighed three hundred and fifty tons.

Eusebius, a profane writer, says that the Lieutenant of Titus tore up the foundations of this temple, so that Christ's remarkable prediction " That not one stone should be left upon another," was literally fulfilled within fifty years after it was delivered.

Ancient Methods of Construction.

I cannot better illustrate the comparison of modern with ancient engineering than by describing, from most trustworthy sources, the probable method of constructing the Pyramids, having particular reference to that at Gizeh, or, as it is often called, after its builder, " The Cheops."

The engineers of that day had iron only in its malleable form, and did not possess the art of converting it into steel, and thus obtaining its high hardening power. They used other metals and alloys, chiefly bronze, or copper, hardened by tin or zinc.

They doubtless split out their large columns from the solid ledges of rocks, like those of the Seven granite, with fire and

14 The French engineers were there years transporting it from Thebes to Paris.

water, as we often now see a farmer split up a hard and troublesome bowlder.

They worked these stones roughly into shape with their bronze tools, and subsequently by the tedious process of rubbing down the surfaces with stones of still firmer texture.

The Pyramid was chiefly made from a soft limestone obtained from the opposite side of the Nile, but some of them came from quarries more than a hundred miles distant.

The smaller stone were hauled on land by oxen, on sledges, and the remains of rude wooden tramways are still extant.

The large stones were hauled by men, who could work in concert, to the sound of music, as shown in some of the Egyptian drawings.

By calculation I find that to haul a stone of three hundred tons, on level ground, a thousand men would be required.

Herodotus mentions one column at Sais, in Egypt, which, by calculation, weighed seven hundred and eighteen tons, which, he says, required two thousand men for three years to haul it from the quarry, about one hundred miles distant.

Our modern wooden scaffolding, and machinery for hoisting was unknown, and instead of them, an embankment was made around the structure, as wide as necessary to move the stones, and this was reached by an inclined plane of earth upon which wooden slabs were laid, and the platform on which the stones were placed rested on wooden rollers. These earth embankments were raised up, as each successive course of stone was laid, and when the structure was completed the earth was removed.

The strong mortars and cements of the Romans were unknown. They had to depend for the stability of their walls upon the massiveness of the stone, and the close fitting of the joints, and by dowels, one set of which were inserted vertically into the beds of the two stones, which were placed vertically of each other, and another set designed to tie the stones together horizontally. Both of these dowels were made either of bronze, or more generally of wood, and those arranged for the horizontal bond were shaped like an "hour glass," that is, dovetailed into each stone. The dowels of bronze have mostly been stolen, but those of wood are frequently found in complete preservation.

This great Pyramid, with a base of seven hundred and forty-five feet square, and four hundred and fifty feet high, contains six and a half millions of tons of stones, and the embankments would have required more than fifty millions of tons of earth.

You will be better able to realize these figures when I repeat that all of the masonry on the Erie Canal amounts to but two and a half millions of tons, or but one-third of that used in this great Pyramid, and that all of the earth which was moved to construct the three hundred and sixty miles of that canal, or for the five hundred miles of the Erie Railway, or even for the two thousand miles of the Pacific Railway.

Each of them only equaled in quantity, that which was probably used, in the place of scaffolding, to hoist and lay the stone of this Pyramid.

Herodotus says that a hundred thousand men were engaged for ten years in building this earthern causeway, and that the same number of men were engaged for twenty years longer in laying up the masonry.

From the amount of earthwork which I have witnessed performed, by freshly imported Africans in Cuba, with baskets of earth carried on the head, as was probably the manner of working at that time, I find that it would require about the number of men and years as stated to build such embankments.

My own calculations show that these [statements cannot be far wrong, and you will observe that they do not include the workmen who were employed in quarrying, cutting and transporting the stone, etc., which would have quadrupled the number.

This great work required the labor of five hundred thousand men for thirty years, and at the present value of such labor in such countries, would have cost five thousand millions dollars.

A modern engineer would construct such a work for one hundred millions of dollars, and with a tithe of the men.

He would quarry the stone by steam-drills, load them with steam-cranes, transport them on the Nile with steam-vessels, and on land with locomotives.

Instead of the fifty millions of tons of earthen embankments, costing ten millions of dollars, he would apply a few hoisting machines, and with a score or two of men, would deliver the stone to the hands of the masons, as fast as they could lay them.

Ancient and Modern Buildings.

I will give you one more example and comparison with ancient engineering.

The Amphitheater or Coliseum of Rome was finished in the golden period of the profession, in the year 79 A. D. It was an oval, and inclosed, and covered an area of six acres. The structure weighed half a million of tons, and could seat seventy thousand persons.

The contrast with this building may be made by referring to the Exhibition buildings of London and Paris.

The London building was eighteen hundred and forty-eight feet long, and four hundred and fifty feet wide, and sixty-one feet high to the Dome roof. The area of the ground floor was seven hundred and seventy-three thousand square feet, or eighteen acres, being three times that of the Coliseum. The area of the galleries two hundred and seventeen thousand square feet, and of the glass nine hundred thousand.

There were three thousand five hundred tons of wrought-iron, and four hundred tons of cast iron used in its construction.

It was built in nine months with the labor of about two thon-sand men.

The Paris building was an oval of two thousand, and fifteen hundred and fifty feet diameter, the outer court being one hundred and ten feet wide and eighty-two feet high, equivalent to a room four thousand and four hundred feet long, and one hundred and ten feet wide, or thirty-one acres area.[15]

There are three Egyptian obelisks in Rome, brought there by Augustus, Caligula and Constantine.

The largest one, now in front of St. Peter's, weighs two hundred and seventy five tons, and the vessel which brought it from Egypt was the largest which had, up to that time, " ever been seen upon the sea."

It is said that when the engineer, Fontana, moved one of these columns to the Piazza del Popolo, in 1589, when it had been raised nearly to its poise, he found that the rope lash-

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15 The dimensions of the Vienna Exposition building and of the proposed Centenary building at Philadelphia, will be found in the Appendix.

ings had stretched so much that the main fall came "block to block," and it was impossible to fleet without lowering the column to the ground.

While he and his associates were discussing how they could gain but one inch more, an old sailor came along, and as soon as he was told of the difficulty, sang out, " Why don't you wet the lashings, you lubbers ?" The engineer took the hint, wet the ropes, which shrank enough to carry the column over the poise, which saved weeks of dangerous labor.

Almost the same thing occurred in my practice. One of the long iron piles which I was driving into the bed of the Harlem had lurched a foot out of line. The most powerful purchases that I could rig would not move it. A sailor, in passing, said: " Make all fast, and wet your falls." This was done and accomplished the desired object.

Moving great Weights.

While upon this subject of transporting great weights, I beg to call your attention to some of those moved in modern times.

The largest stone in any erection in the world is the granite base of the column of Peter the Great at St. Petersburg, which weighs three millions pounds, or one-fifth more than the largest stone at Baalbec. It was transported fifteen miles by land on a wooden tramway, with cannon balls for rollers.

I have already mentioned the transport of the column of Luxor, and I might have added that it rests upon a single block of granite of one hundred and twenty tons, brought from Brittany sixty miles by land.

There is a stone, the tazza, in the Treasury building at Washington, which weighed, when quarried, three hundred tons, and, after being roughly worked down to one hundred tons was transported by sea six hundred miles. And another, in the same building, a buttress-cap, of the same quarry weight, was roughed off to eighty tons before shipment, and, as now finished, weighs sixty tons.

The Great Eastern steamship was launched sideways, being forced a thousand feet by very powerful machinery. At this time the hull weighed upwards of eight thousand tons.

The four tubes of the Britannia Bridge each weighed fifteen hundred tons and were launched, transported a mile through a strong tideway, and then elevated one hundred feet perpendicularly.

But we have only to refer to the " house moving " of recent times, when a large brick building has been moved a considerable distance ; or to greater ones, when whole blocks of large fine cut stone buildings in Chicago have been elevated ten or fifteen feet without disturbing the occupants in their regular avocations ; and at the present time, when all of the houses on one hundred and thirty acres of a compact part of Boston are being raised thirteen feet; and also at Sacramento, where the whole city is being raised about fifteen feet.

Ancient and Modern Ships.

It may be interesting to compare the dimensions and tonnage of some of the largest vessels of former times with those of the present.

The Ark was four hundred and fifty feet long, seventy-five feet wide, and forty-five feet high, and if its displacement corresponded with the modern form of large vessels, its tonnage was from twelve to fifteen thousand tons.

" Show 'ships were built by Hiero and the Ptolemies of from five hundred and sixty to five hundred and ninety feet long, from sixty to seventy-six feet wide, and eighty to one hundred feet high. These vessels never went to sea, and could only be maneuvred in calm water. They were manned by four thousand rowers, four hundred sailors, and twenty-eight hundred and fifty fighting men. Their tonnage was less than that of the Ark.

The British ships in the time of Julius Csesar were built " with the keel and frame of light wood. A sufficient number of elastic twigs were interwoven between the ribs to give strength to the sides, which were afterwards covered with hides."

" The first barks used on the Nile appear to have been formed of small planks of the Egyptian thorn, about three feet square, lapt over each other like tiles and fastened by treenails," * * * The joints and seams were caulked with the papyrus.

" Hiero built a merchant ship of four thousand tons burthen, and the Egyptians, at a still earlier period, built the " Iris," one hundred and eighty feet long, forty-five feet broad, and forty-three feet from the keel to the upper deck." * * * " The burthen was about one thousand nine hundred tons." One author, inclined to exaggeration, says of this ship: " She was capable of carrying as much corn (wheat) as to have supplied all Greece for twelve months."

In the time of Caius Caesar " a ship was built to convey the celebrated obelisk to Rome, and carried one hundred and twenty thousand bushels of corn merely for ballast."

The galley built by Philopater " had oars fifty-seven feet long loaded with lead in the handles to balance them." * * * "The speed was from forty to sixty leagues in twenty-four hours."

" The Sovereign of the Seas, built in 1631, the largest ship of her day, was two hundred and thirty-two feet long over all, had a keel of one hundred and twenty-eight feet, main width forty-eight, and depth of seventy-six feet from the keel to the top of the stern lantern."

The Great Eastern is six hundred and ninety-five feet long, eighty-two feet beam, hold fifty-six feet deep, and draft when loaded ready for sea, thirty feet, and a tonnage of twenty-two thousand five hundred. Her hull, engines, etc., weigh twelve thousand tons, and she has a carrying capacity of eight thousand tons of freight, and four thousand passengers, or she could transport ten thousand troops with all their munitions.

There are some modern men-of-war of nearly nine thousand tons displacement.

The Cunard and American sea steamers, those on the Sound and Hudson River, and even on the Mississippi, range from three thousand to five thousand tons.[16]

Steam Engines and Pumps.

The largest steam engines in the world were those used for draining Harlem Mere, in Holland.

The steam cylinders were twelve feet diameter and fifteen feet stroke, and each one of the three engines drove eight water pumps of sixty-three and seventy-three inches diameter, and ten feet stroke.

They were employed for seven years in pumping the water out of the lake to the depth of sixteen feet below the level of the sea, from an area of fifty-six thousand acres, or twice

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16 As late as the fourth century the Romans employed sea merchant vessels made of wooden frames covered with hides instead of plank. Those of seventy tons were called "very large vessels."

that of Manhattan Island, which involved the removal of eight hundred million tons of water.

Each of these engines were capable of delivering two hundred millions of gallons of water per day, and when the three engines worked together would discharge a volume six times as great as that which the Croton Aqueduct is capable of delivering.

The next largest pumps in the world are those at the United States Dry Dock, at Brooklyn (which are sixty-three inches diameter, and ten feet stroke), and capable of delivering thirty millions of gallons of water^ per day, from a depth nearly three times as great as that of the Harlem Mere.

The steam engines next in size to those at Harlem are those of the Bristol and Providence steamers, with cylinders of nine feet two inches diameter, and twelve feet stroke.

A new pumping engine in London and one in Cincinnati have also cylinders of this size.

Bessamer Steel.

One of the greatest of modern discoveries is the process of converting great masses of pig or cast-iron into steel, in twenty minutes, without the aid of fuel or furnace, at a cost of half a cent a pound, and developing a heat heretofore unknown or unused in the arts, and a light equal to the combined effect of all the gas-burners in the city of New York.

When it is remembered, that by the ordinary process, it requires several hours to decarbonize cast-iron arid render it malleable, and then a fortnight to recharge it with the small quantity of carbon to convert it into steel, arid another smelting, to produce cast-steel, thereby increasing the cost of the product four-fold, you will see the extent of the changes which this discovery is destined to introduce in engineering structures.

Steel of more than twice the strength of wrought-iron will soon be furnished at almost the same price.

Already we have witnessed the commencement of this revolution in the substitution of steel for iron rails upon all our leading railways.

Apprehensions have been expressed that steel, which is usually considered so brittle, will not withstand the heavy shocks of the locomotives in our severely cold climate. But I can say, from my own experiments and examinations here and abroad, that steel rails, properly made, are really very much tougher and much less liable to break in extreme cold weather than those made of the best of wrought-iron.

In fact, by this new process the rails are necessarily made of the exact degree of hardness and toughness that is demanded, and the English engineer now prescribes the extent of the carbonization of the iron, with a limit of variation of only one-tenth of one per cent.

The tires of locomotives, the axles of cars, the large rods of steam-engines, large and small shafting, and many other of the most important parts of machinery are now made of this metal, and we shall soon find it in common use, wherever strength or security is demanded.

The Seven Wonders of the World.

The Seven Wonders of the ancient world were :

1. The Egyptian Pyramids.
2. The Mausoleum of Artimesa.
3. The Temple of Diana at Ephesus.
4. The walls and hanging gardens at Babylon.
5. The Colossus of Rhodes.

6. The Statue of Jupiter Olympus; and,
7. The Pharos of Alexandria.

If seven were popularly selected from the works executed in our day, they would be::

1. The Thames Tunnel.
2. The Great Eastern Steamship.
8. The Atlantic Cable.
4. The Britannia and Niagara Bridges.
5. The Erie Canal.
6. The Modern Ordnance; and,
7. The Pacific Railway.

If the engineer was called upon to name works in which the highest degree of professional skill has been exhibited, he would probably make some changes in this list.

The Studies of a Modern Engineer.

Probably few of the audience are aware of the hours of thought and study which are required of the engineer in the calculations and preparation of the plans for an important public work.

For an illustration of this I will refer to the Britannia Bridge, built by the celebrated Engineer Robert Stephenson.

Mr. Stephenson began his investigations as follows ::

There are but three kinds of bridges: 1. The arch, depending wholly upon the strength of the metal in compression;

2. The suspension, dependent wholly upon the tensile strength of its cables; and

3. The girder, in which some of its members are subjected to strains of compression, and some of them to tension.

Bridges are often built combining two of these principles, but the difficulty of producing unity of action between them has led engineers to generally confine themselves to but one of them.

Mr. Stephenson's first design was a bridge with arches of cast-iron, of one- hundred and fifty feet span and fifty feet rise, with the center placed at an elevation of one hundred feet above the level of the sea channel, which they spanned.

But the Admiralty, which had the legal control over such structures, declared that " no bridge should be erected which did not leave a clear headway of one hundred feet for the *whole* width of the channel."

The design of this bridge has been greatly admired, and many regrets have been expressed that the structure was not allowed to be built upon that plan.

Mr. Stephenson's next design was a suspension bridge with a stiffened platform, but the difficulty of combining two such opposite principles in the same structure led him to dismiss the system of supension as a permanent support, and his next design was a girder, merely using suspension chains instead of scaffolding.

Our own engineer, Roebling, the Pontifix Maximus of the day, has practically demonstrated that these two principles may be usefully, safely and economically combined, and has applied them to spans of more than twice those of the Britannia bridge, and is also prepared to undertake those of four times that span.

Unprofessional persons will better understand the difficulty of constructing bridges of long span when it is stated that the strains increase with the length of the spans. That is, that a bridge of two hundred feet must be twice as strong as one of one hundred feet; that the Niagara bridge is subjected to strains twice as great as those of the Britannia, and that the proposed bridge from New York to Brooklyn must be twice as strong as that at Niagara.

Having determined upon the girder, Mr. Stephenson next proceeded to consider its proportions.

A green willow wand, if laid upon two supports, not too far apart, will show the bark with a smooth surface on all sides.

Now, if a weight be suspended from the middle, the wand will be bent downward; it will be noticed that the bark upon the upper side is wrinkled up, and on the lower side that it is stretched out.

The first is the result of the compression of the fibres of the bark, and the second that of their tension. That is, all of the fibres of the bark on the upper side are forced together, and those on the lower side are drawn out.

It will also be observed that about midway in the depth the bark remains smooth, not having been affected by either compression or tension.

This is called the neutral axis, and this part of the stick is not subjected to any strain, except to hold the upper and lower parts together.

If a hole is bored out of the middle of the stick, it will be found that so far from weakening, it has given it the power to sustain as much more weight as that removed.

Reasoning in this manner, the engineer determined to make experiments to ascertain how much of the interior could be removed with advantage.

His first trial was with a cylindrical hollow beam of wrought iron, heavily plated on the top and bottom, and as it yielded either at the top or bottom, he kept on strengthening that part.

Meanwhile he had gradually changed the form of his tube from circular to elliptic, and finally to a rectangular shape, which his final experiments determined as the best form.

He spent a year or more in these experiments, aided by Fair. bairn, one of the best mechanicians of the day, and Hodgkinson, a distinguished mathematician and scientist, by means of which, the best form and proportions of the different parts of the girder were determined from a model of forty feet length.

Other experiments were made, to determine the strength of the riveting, of the lateral strength of the beam against gales of wind, of the strength of the stone and brick upon which the girders, etc., weighing eight thousand tons, were to rest, all of which experiments cost upward of fifty thousand dollars ; but they enabled the engineer to lay down his plans with great certainty, saving on the one hand any unnecessary weight of metal in any part of the tube, and on the other from the weakness of some part, which would have lessened the strength and value of the whole structure.

Before a blow had been struck upon this work, the engineer had completed his plans so perfectly that he had even marked out the position and size of every rivet in the tubes.

Many volumes have been written descriptive of this work, and they have been translated into the language of every civilized nation.

It is true that the engineer would not now duplicate such a girder, but a quarter of a century ago it was the boldest engineering work of its kind.

A few years ago Prof. Airey, the astronomer royal, a member of the Institution of Civil Engineers of Great Britain, received the highest award of merit from that Society (the Telford gold medal) for an essay on a particular method of computing the strains upon the different members of a truss, but particularly of a most curious and interesting application of the changes in the musical tones which steel rods give forth, as they are more and more strained by the addition of weights suspended from them.

A model truss was exhibited, all of its parts having been made from steel of a perfectly homogeneous character.

Every piece or member of the model truss was made in duplicate, and the two were tested as to the correspondence of their intonation, when unloaded and when strained with different suspended weights.

The model truss was then put together, and loaded with its anticipated weight.

The duplicate piece of steel representing any particular member, was then suspended and gradually loaded until its resonance became the same as its corresponding member in the loaded truss.

This added weight then accurately represented, first, the effect of the weight of the model itself upon that member, and next of the added load.

Each member of the truss was in like manner tested by loading its duplicate.

These musical experiments confirmed Prof. Airey's method of calculating the strains on the different parts of the model of the bridge truss which he exhibited during his address.

Great Engineering Projects.

I will close this address with a reference to some of the great engineering works which have been projected in our day.

In a recent paper, emanating from a board of distinguished engineers, they say: " There is danger that, under the incentives of these wonderful achievements, the engineer may be led either to attempt impossibilities, or, what is more likely, to venture too far into an untried field of labor; " and they add,

" He (the engineer) would fail in his duty, and in a proper comprehension of his mission, if he allowed himself to project plans merely for his own personal eclat or aggrandizement, or if he did not confine himself to the most safe, practicable and reasonable methods of accomplishing the results which are demanded of him."

These conservative opinions, intended for the cautious capitalist, were doubtless those of a large portion of the members of that convention, but, among the engineers then present, were some who had themselves left the routine rules of the profession and demonstrated the possibility of plans which had previously been questioned.

When we use the word "impossible," it as often indicates that our knowledge or reasoning faculties are insufficient to grasp the subject presented, as that the subject itself is in conflict with the laws of nature.

Not very long ago it would have been hazardous to have advocated steam navigation, railway locomotion or electric telegraphy.

When Dr. Lardner was lecturing against the possibility of a vessel being able to cross the Atlantic by steam, the Sirius and Great Western steamers were on their first voyage from England to America.

While the most eminent engineers were building railways to be operated by horses and stationary engines, Stephenson produced the Rocket locomotive, and while the world was ridiculing Morse, the leaders of the Presidential Convention at Baltimore were conversing with the candidates in Washington through the telegraphic wires.

Among the great projects of the age are those for building canals, railways, bridges, tunnels and steamers.

It -would be both presumptuous and hazardous to designate which of these projects are practical and which are chimerical, but those of each class which are most feasible I will name in order.

In canal work, we have a project for one around the falls of Niagara ; again, an enlarged canal between the interior lakes and the Hudson, suitable for vessels of a thousand tons; the Suez canal (a rebuild of the one made by Necho, 610 B. C.); a canal across the Alleghanies, between the navigable waters of the Ohio and James rivers; a canal through the Nicaragua lakes, or across the Isthmus of Darien, and one from Lake Huron to Ontario.

In railways, we have the Pacific, on the eve of completion, the Mount Cenis in rapid progress, the one across the South American continent, from Rio Janeiro, begun, and others of magnitude and numbers too numerous to mention which have been commenced.

Of bridges, we have those in progress across our great western rivers; one proposed over the East river at New York, of one thousand six hundred feet clear span; two over the Hudson, above and below West Point, each of twelve hundred feet span; another across the Straits of Messina, covering the Scilla and Charybdis, with clear spans of a thousand meters, or nearly two-thirds of a mile each, and with piers of seven hundred feet high, half below and half above water; and finally, the modern "Pons Assinorum," a bridge project across the Straits of Dover, sixteen miles long, in clear spans of two miles, with piers of a thousand feet or more in depth.

In tunnels, we have that of Mount Cenis, nine miles, and the Hoosac, of five miles in length, both in rapid progress; one of wrought-iron tubes (a sub-aquean bridge) under the

Thames, and another under the Chicago river, almost completed ; tunnels also proposed under the East and Hudson rivers at New York, under the Ganges at Calcutta, and under the Straits of Dover.

Conclusion.

After the annual dinner of the Smeatonian Society in London, two years ago, this subject (the tunnel under the Straits of Dover) was discussed, and the chairman called for my opinion, remarking that my countrymen were noted for projecting (and accomplishing, he added) some of the boldest engineering schemes. He said:

" Do you regard the tunneling of the Channel a feasible project ?"

It being a post-prandial discussion, I felt at liberty to reply as follows:

" Our late President of the United States (Mr. Lincoln), as you know, had a happy faculty of expressing his opinion by an illustrative story, and with such high national authority, I will adopt the same method of answering your question."

During the Peninsular war, an officer of Wellington's army, on his march to attack a strong fortress in Spain, was met by a brother officer, who naturally inquired the object of the movement.

' What,' said he, ' to capture (so and so) ? Why, man, it is impossible.'

' Impossible P' repeated his friend, ' not at all, for I have the *Duke's* order in my pocket.'"

And so with the modern engineer. With the *Banker's* order in his pocket, he considers almost *nothing* as impossible.

APPENDIX A.

(Referred to on page 16.)

The Length of the Railways of the World.

Country.	Year.	Miles.
North America.		
United States		60,178
Canada		2,928
Mexico		800
Honduras	1873	144
		63,550
South America.		
Chili	1873	452
Argentine Republic	1873	875
		57
		375
Paraguay		44
		410
		65
		2,278
Europe.		
Great Britain	1873	15,814
Germany		13,066
France		10,333
Austria (etc.)		7,529
Russia		7,297
Italy	1871	3,895

Spain		3,801
Sweden and Norway	1S73	1,049
Belgium		1,892
		1,045
Switzerland	1871	820
		530
Turkey		488
Country.	Year.	Miles.
Europe.		
		507
		453
i i		68,519
		4,182
Egypt		737
Cape of Good Hope		134
Australia	1870	1,058
		6,111
Railways total miles		149,458

APPENDIX B.

(Referred to on page 19.)

Dimensions' of various Canals

NAMES.	*Length, miles.*	*Width of surface feet.*	Width of bottom, feet-	*Opened, year.*	Locks. *Number.*	*Length, feet.*	*Width, feet.*	*Depth, feet.*	*Rise, feet.*	Fall, feet.
CANADIAN.	81/2	]20	80	1848	5	200	45	16&9.	45	
Beauhamois	*111/4*	120	80	1845	9	200	45	9	82	
Cornwall	111/2	150	100	1843	7	200	55	9	48	
Galops	3/4	90	50	1847	1	200	45	9	4	
	4	90	50		2	200	45	9	12	
	71/2	90	50		8	200	45	9	16	
Welland	431/2 271/4	70	40	1846	27 27	150	26A	101/4	207 330	
Rideau Route	133	80	60	1832	59	134	33	5	356	177
Richelieu	12	60	36	1843	9	118	23	7		
Welland Enlarged	30	150	100	*began* 1873	25	270	45	12	330	
UNITED STATES. Sault St. Marie New York Canals	513	200 40	150 28	1825	2 338	350 90	70 15	12 4	19 2	310
Erie Enlarged	352	70	52	1862	72	110	18	7	6	55
Delaware and Hud-son	108	44	26		107	100	15	6	y	50

Delaware and Raritan	43	75	54	18	220	24	7	I	16
Delaware and Chesa-peake	14	66	42	4	220	24	8		
Albemarle and Chesa-peake.	14	125	100		220	40	7		
Chesapeake and Ohio	191	70	52		**100**	**15**	6	6	**916**
Kanawha	147	40	28				4	1	
Illinois and Michigan	102	60	42	2			6		20

The Suez Canal was completed Nov. 15, 1869. It is 120 miles long, 330 feet wide at the water line, and has 26-j feet depth of water. There is a tide lock at each end, 330 feet long and 70 feet wide.

The Imperial Canal of China, built in the seventh century, is 720 miles long, with five or six feet depth of water, except in the dry season, when it is only three feet deep.

. The Ganges Canal was commenced in 1848 and completed in 1854, at a cost of seven millions of dollars. It is 170 feet wide at the surface, with ten feet depth of water.

The main line, including the river improvements, is 525 miles long, and including its branches, 900 miles long, and irrigates a million and a half of acres.

The Amsterdam Canal, 51 miles long, with 135 feet width of surface and 21 feet depth of water, cost four and a quarter millions of dollars.

The whole Length op all the Canals in' the World, is as follows :

In the United States and Canada...............5,410 miles.
In Europe....,... 12,552 miles.
In Asia and Egypt.................................... 6,420 miles.
24,382 miles.

The above statement was copied from Col. Conkling's report.

APPENDIX C.

(Referred to on page 20.)

Dimensions of some large Bridges.

Britannia Bridge, Menai, Great Britain, iron tubular, spans 460 feet. Victoria Bridge, Montreal, iron tubular, spans 330 feet.

Severn Bridge, Great Britain, cast iron arch, spans 200 feet, rise 20 feet.

Chestnut Street, Philadelphia, cast iron arch, span 185 feet, rise 20 feet.

Susquehanna Bridge, Maryland, wood and iron truss, span 300 feet, 30 feet wide.

Missouri Bridge, St. Charles, truss, span 325 feet.

Steubenville Bridge, Ohio, truss, span 320 feet.

Fryburg Bridge, Switzerland, suspension, span 889 feet.

Niagara Bridge, New York and Canada, suspension, span 821 feet. Wheeling Bridge, Virginia, suspension, span 1010 feet.

Niagara Falls Bridge, New York and Canada, suspension, span 1256 feet.

Brooklyn and New York Bridge,[17] suspension, span 1600 feet.

17 In process of construction.

APPENDIX D.

(Referred to on pages 19 and 28.)

Extracts from Wm. J. Me Alpine's Report to the Legislature of New York, for 1852,

ON TRANSPORTATION.

" An investigation of the comparative advantages of the several channels of communication between the sea-board and the interior requires an examination into the cost and charges of transport by the various modes of land and water conveyance."

" The charges cannot be relied upon in this investigation because they fluctuate on the various routes, and on the different articles conveyed; competition reducing them to a minimum and monopoly raising them to a maximum."

" The cost, however, furnishes a more reliable basis for comparison, as the elements upon which it depends are usually affected alike on the'different routes."

"These elements consist of loading, conveying, discharging, warehousing, insurance, and in artificial channels, the necessary expenses of maintenance-and cost of construction."

* * * "The cost of movement on a canal depends upon the relative sectional areas of the'boat and'of the canal, upon the actual size of the two, and upon the elevation'(Of depression)* to'be overcome. The cost of movement upon a railroad 'depends upon' the elevation to be overcome, the rate of its gradient, the curvature, and the limited capacity in comparison with the cost."

* * * " In arriving at the general results (the actual cost of transport by each mode of conveyance, applied to the several lengths of each on the channels of trade between the interior

and the sea-coast), it will not be necessary to regard fluctuations of trade and commerce tending to increase or diminish the cost of transport which are of only a temporary character."

"The following table shows the distances by sailing vessels, and the ordinary charges from American ports to England, etc. * * * The cost may be assumed at two-thirds of these charges." .

Table of Charges.

<table>
<tr><td></td><td colspan="3">To Liverpool.</td><td colspan="3">To Havana.</td><td colspan="3">To Rio Janeiko.</td></tr>
<tr><td>1851.
FROM.</td><td>Miles.</td><td>Per Voy-age. Dolls.</td><td>Ton. Pr Mile. Mills.</td><td>Miles.</td><td>Per Voy-age. Dolls.</td><td>Ton. Pr Mile. Mills.</td><td>Miles</td><td>Per Voy-age. Dolls.</td><td>Ton. Pr Mile. Mills.</td></tr>
<tr><td>Quebec .....</td><td>2910</td><td>$1100</td><td>3.75</td><td>1960</td><td rowspan="2">$4 00</td><td rowspan="2">2.70</td><td>6010</td><td rowspan="2">$4 oo</td><td rowspan="2">0.75</td></tr>
<tr><td>Boston......</td><td>8020</td><td>5 25</td><td>1.74</td><td>1480</td><td>5310</td></tr>
<tr><td>New York...</td><td>3150</td><td>5 00</td><td>1.60</td><td>1250</td><td>3 00</td><td>2.40</td><td>5240</td><td>4 00</td><td>0.76</td></tr>
<tr><td>Philadel-phia,</td><td>3295</td><td>5 50</td><td>1.70</td><td>1220</td><td>4 00</td><td>3.27</td><td>5000</td><td>5 00</td><td>1.00</td></tr>
<tr><td>Baltimore</td><td>3530</td><td>5 75</td><td>1.60</td><td>1215</td><td>5 00</td><td>4.11</td><td>5000</td><td>6 00</td><td>1.20</td></tr>
<tr><td>Richmond</td><td>3395</td><td>6 00</td><td>1.70</td><td>1170</td><td>5 50</td><td>4.70</td><td>5000</td><td>6 00</td><td>1.20</td></tr>
<tr><td>New Orle-ans,</td><td>4755</td><td>7 50</td><td>1.60</td><td>595</td><td>4 00</td><td>6.72</td><td>6555</td><td>7 00</td><td>1.06</td></tr>
</table>

Table of the cost of Transport per ton per mile from Wm. J. McAlpine's report for 1852.

Ocean, long voyayes (3,000 miles and more)................1 mill.
" short voyage (2 mills for 1,000 to 1,500 miles)
from................................ 2 to 4

Interior Lakes, long voyage, 1,000 miles and more..			2	mill.
“ short voyage, 500 miles and less....	3	to	4.	“
Rivers, similar to the Hudson			n	“
“ similar to the St. Lawrence and Mississippi.			3	“
“ tributaries	5	to	10	“
Canals, Erie enlarged			4	“
“ other large canals, but shorter	5	to	6	“
“ of the ordinary size			5	“
“ “ “ with great lockage	6	to	8	“
Railroads, transporting coal (and other fixed business)	6	to	10	“
“ for the usual traffic with favorable grades,			121/2	“
“ with steep grades, irregular traffic, etc...	15	to	251/2	“

“ These rates, when applied to the several routes and conveyances, must be increased to pay for maintenance and interest. On the Erie canal this was assumed at one dollar a ton.”

The increase in the Value of labor and materials required in transportation and in the value of money, between 1852 and 1873, has been from one-fourth to one-third, but is in exactly the same ratio as given by the above table.

A statement given to me in May, 1873, by one of the largest shipping houses in New York, for the average fair, charges by sail from New York to Liverpool, was $6.25 per ton for grain, beef, pork, etc., and returning $3.75 per ton, chiefly iron. The charge by steam is one-third greater.

The distance is 3,442 statute miles, making the present average charge nearly $1\frac{1}{2}$ mills per ton per mile by sail, and 2 mills by steam.

The charges by sail to Valparaiso (12,000 statute miles) is $11 out and $20 returning, equal to $1\frac{1}{2}$ mills per ton per mile.

The, charges by sail to San Francisco, around Cape Horn (16,000 statute miles), is on coal $10 per ton of 2,240 pounds, and general freight $12, equal to $\frac{2}{3}$ of a mill per ton per mile on coal, and f on other freight.

The charge by steam from New York, via Panama to San Francisco (6,100 statute miles), is about the same as by sail around Cape Horn, equal to $\frac{1}{3}$ of a mill per ton per mile on goods, freight delivered in 30 days. The time by Cape Horn is from 100 to 120 days.

The charge by railway from New York to San Francisco, 3,400 miles, on general freight, is from $60 to $150 per ton, equal to from 18 to 45 mills per ton per mile.

The charge from Montreal to Liverpool averaged $6 per ten by sail, and $8 by steam, equal to $1\frac{1}{2}$ and $2\frac{1}{2}$ mills per ton per mile.

The charges for grain, etc., by sail on the Lakes in 1873, were 5 mills per ton per mile, and by steam 6 mills; and by Erie Canal 6 mills. At the same time the charges by railway from Chicago to New York were 10 mills in the summer and 14 in the winter.

The average charges by railway from Chicago to Buffalo for the whole season, and for all classes of freight, were 2.43 cents per ton per mile in 1868, 2.34 cents in 1869, 1.5 cents in 1870, 1.39 cents in 1871, and 13.7 mills per ton per mile in 1872.

APPENDIX E.

(Referred to on page 28.)

Hon. Samuel B. Ruggles in 1869 prepared with great care a table of the cereals annually produced by each country of Europe and by the United States.

The following is an abstract:

COUNTRY.	*Population.*	*Total product, Imp. Bushels.*	*Ratio of business to population.*
Russia	63,883,867	1,484,437,500	21.2
Germany	38,768,291	664,411,100	17.1
France	38,954,782	717,215,996	18.3
Austria and Hungary	35,444,876	571,254,765	16.1
Great Britain	30,380,787	380,887,930	12.5
Sweden, Norway, Low Countries..	18,813,625	244,517,511	13.
Italy, Spanish Peninsula Danubian Provinces and Turkey)	63,877,665	691,791,799	10.9
Total of Europe	296,123,293	4,754,516,604	16.
United States in 1868	39,000,000	1,405,449,653	36.

The cereal crop of the whole of the United States in 1871 was fifteen hundred millions of bushels, or nearly forty millions of tons.

The ten western and northwestern States produced in that year more than a thousand millions of bushels, or twenty-five millions of tons, valued at home at five hundred millions of dollars.

The tables from which this estimate is derived, show that the value of the grain lessens rapidly as the farms are more remote from the navigable waters. Corn is valued at 25 to 29 cents in Iowa and Nebraska, and 59 cents per bushel in Michigan, and wheat is valued at 90 cents in the former and 132 cents in the latter.

While the whole producing West is deeply interested in cheapening the cost of transportation between the main water lines and the " cereal frontier " sections, where the demands of new emigrants and railway constructors have ceased, it has become a question of commercial life or death to secure not only cheap transport to the great water lines, "but also the cheapest through lines.

The neat cattle, for slaughter, within these ten States, amount to five millions annually, and the swine and sheep to thrice that number, aggregating three and a half millions of tons, more than one-fourth of which reach the Atlantic markets, chiefly that of New York.

In 1872 there were nearly five million hogs slaughtered and packed for export from the West, amounting to five hundred and fifty thousand tons.

The cereals shipped from the Western Lake-ports amounts to one hundred and fifty millions of bushels, and by railway, probably, fifty millions more.

The cereals received at the lower end of Lake Erie by lake is, probably, eighty-five millions bushels, and by railways forty-five millions. The shipments by the Erie Canal are fifty millions bushels, and probably half that quantity by the Central and Erie Railways.

The amount of cereals received at the Atlantic cities is one hundred and sixty millions of bushels, and that exported to foreign countries, chiefly from New York to Great Britain, is one hundred millions of bushels.

Receipts and Shipments by Water and Railivay, showing the proportion of each at various places.

	Tons Receipts.	*Tons Shipments.*
Chicago		
Of all articles by the four		
railways.. lake[1]	1,430,726	2,077,055
Totals	2,965,402	1,847,240
Milwaukee		
Of flour and grain by railway		
lake	4,396,128	3,924,295
Montreal	800,000	almost none
Of flour and grain by railway	almost none	800,000
railway	90,000	23,000
canal and river,	356,000	368,000
Totals		
	446,000	391,000

Analysis of the Business of the Trunk Railways for 1872. •

	New York Central.	*Erie.*	*Pennsylvania.*	*Baltimore and Ohio.*	*Lake Shore.*
Length Of trunk line, miles	442	459	358	379	540
Cost in millions Of dollars					
Number of locomotives " applied to freight " of	63	109	42	39	84
freight cars.. Mileage of the freight	447	488		383	418
trains	230[2]	250	10,000	311	250
Mileage Of the freight, Tons Of freight carried,	10,983	10,638	1,187,107,000	8,251§	8,637
Through freight East, tons	7,911,257	3,004,051	7,844,778t	7,121,7955	600,000,000
	1,020,908,885	950,708,902	879,461	910,855,695	4,382,243
	4,293,965	5,564,274	412,385	4,000,000*	
Through freight West, tons		893,685	1,291,846	750,000	
Through freight in both directions, tons, Average	2,250,133 250	369,196		300,000	
load per train	127[3]	1,262,881		1,050,000	
	230	220			
Average load per train calculated, tons..		105			130[4]
Average distance freight was moved, miles...		170	152	150[5]	208
Average distance of way freight, miles...	1.67	1.52	1.42		1.37
Average rate charged per ton per mile, cts.	34,000	36,000		30,000	33.000
Mileage Of engines per annum					17.000
Mileage Of cars per annum					

1 This lake tonnage (4,812,642 tons), would require twenty-five thousand cars and six hundred locomotives to haul it from Chicago to Buffalo, based upon the actual work done by the cars and engines in 1872, provided it could be hauled regularly throughout the year; this would be impracticable, and therefore it would require three times as many locomotives and five times as many cars as the Lake Shore Railway now uses to perform the lake business between Chicago and Buffalo, and these numbers must again be increased one-half to provide for the business from the other lake ports.

2 Estimated.

3 Calculated.

4 Including 3,669,071 tons of coal, and excluding 614,757 tons of fuel for company's use.

5 Includes mileage of 72 passenger engines.

APPENDIX F.

(Referred to on page 28.)

Abstract of Replies

To questions of the Canal Commissioners of Canada, by Boards of Trade and Forwarders in 1871, giving the results of the best opinions thereon :

1. To provide for the most suitable navigation through the lakes to tide water, the locks of the Welland.Canal should be enlarged to a length of two hundred and fifty to three hundred feet, a width of thirty-five to forty feet, and a depth of water of fourteen feet.

2. The Boards of Trade of the Upper Lakes recommends vessels of one thousand to one thousand five hundred tons as the best adapted to carry produce from Chicago, etc., to ports on Lake Ontario with the greatest economy. Several persons recommend vessels of not exceeding eight hundred tons.

Steam propellers are found almost as economical as sail vassels, regard being had to the greater number of trips which they can make.

12. Taking into the account time, insurance and interest as elements of cost, steam vessels (propellers) cannot carry freight on this route as cheaply as sail vessels.

Yet both are necessary to meet the strong competition of the short line railways.

F. G. Holcomb, of Toronto, states that the theory of practical men is, " that a vessel, to be profitable, should have at least one ton of cargo capacity for each mile of the route it is designed for."

The larger the vessels within the above limit the less will be the proportionate cost. " For instance, the only difference in a vessel of ten thousand or twenty thousand bushels will be one or two additional men."

Transport by steam costs less, if there is quick dispatch ; (that is, in loading, unloading, lockage, etc.)

13. What is the cost and daily working expenses of sailing and steam vessels of five hundred and one thousand tons capacity ?

In Dollars.

	Cost of sailing Vessels.				Cost of Steam Vessels.			
	500 Tons.		1000 Tons.		500 Tons.		1000 Tons.	
AUTHORITY.	Vessels.	Daily Expense.	Vessels.	Daily Expense	Vessels.	Daily Expense.	Vessels.	Daily Expense.
Board of Trade.								
Chicago	30,000	40	40,000	43	50,000	130	80,000	190
Milwaukee	25,000	50	40,000	70	50,000	100	80,000	125
Detroit	25,000	25	45,000	35	45,000	100	75,000	120
Oswego	25,000	60 :	60,000	100	45,000	120	75,000	160

17. The general opinion of the Montreal merchants and forwarders is that the produce from the Western States can be transported the cheapest in large vessels to the east end of Lake Ontario, and thence to Montreal by transfer (of grain) into barges.

Mr. Stuart, of Detroit, says: " There is no kind of transportation that can compare with that by barges."

The gentlemen of Chicago and other places West, and some of those of Oswego, agree in the above opinions.

Others assert that when the Welland Canal is enlarged to convey vessels of one thousand to one thousand five hundred tons, it will be much cheaper to convey the cargo directly to the side of the sea-going vessel.

19. " Vessels adapted for the ocean are too heavy, too costly, and in many other respects wholly unfit for economically navigating the Interior Lakes." " They are too heavy in frame, masts and rigging, and too difficult to

move and control in the rapids, and in entering and passing through the canals."

All of the correspondents agree that it would be inadvisable to have the same craft navigate the lakes and the ocean.

The Board of Trade of Toronto says: "Iron is now received from the ocean ships in Quebec, and laid down in Chicago for three dollars and fifty cents per gross ton by water even with our present imperfect facilities," (less than two and one-half mills per ton per mile). " It is well understood that the cost of haulage on a railway for the same distance is at least ten dollars per ton, and therefore it is impossible for the rail to compete successfully with water."

30. Interrogatory: " It takes from twenty to thirty minutes to pass the locks of the Welland Canal, and twenty hours for steam and thirty hours for sail vessels to go through the whole canal."