ENGINEERING PRACTICE AND EDUCATION

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A course of six lectures prepared for delivery in the Lowell Institute; three of which were not given on account of the sickness of the author.

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ENGINEERING PRACTICE AND EDUCATION.*

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If any one among my hearers expects me to begin this lecture by giving a definition of the words *Engineering* and *Engineer*, I am afraid he will be disappointed. Definitions are attempts to describe, or to give the distinguishing characteristics of the thing defined, in a very few words. To give them is comparatively easy when the things defined are of limited scope; but the more extended the scope, the more difficult does it become to circumscribe them within the bounds of a definition.

Indeed, the term *Engineering* has been used with different significations at different times, and what has been its accepted meaning at any one time has depended upon the particular condition of the world's industrial progress at that period.

Without going into a great many details, I may say that the definition of the profession of the *Civil Engineer*, adopted by the Council of the British Institution of Civil Engineers, in 1828, was, "the art of directing the great sources of power in Nature for the use and convenience of man." Such a definition as this is not only vague, but, if taken literally, it would include a range of work far more extensive than that which has ever been or is now understood as the province of the engineer. Nevertheless, the converse is true of the engineer (omitting the limiting term civil), *i. e.*, the engineer must, in the practice of his profession, direct the great sources of power in Nature for the use and convenience of man.

* A series of six lectures prepared for delivery in the Lowell Institute, in Boston, Mass.; the last three of which were not given on account of the sickness of the Author.

At one time, when the science of engineering was still quite limited in its scope, there were only two designations used, viz.: military engineering and civil engineering, the latter term denoting all engineering which was not military.

Later on, as the science, and hence the scope of engineering, advanced, and as engineers began to devote themselves to special lines of work, there arose a large variety of designations, some of which are: civil engineering (no longer used in the original sense), mechanical engineering, mining engineering, etc., and it was assumed that these professions were quite distinct from each other. Indeed, this idea seemed to be in accord with the natural drift towards specialization, and in the line of progress. Now, however, that the tendency towards specialization is ever on the increase, and that progress has gone farther, I think that any one who will examine the facts carefully, and in a judicial frame of mind, will be satisfied that while all these different kinds of engineers are applying their art to a specialty, nevertheless, the art is one, and the functions of the engineer comprise one definite, though wide and extensive, range of work.

We will now proceed to consider some examples of the engineering works of the world of different kinds, in such detail as our time will allow; and when we have done this, whether we do or do not attempt to formulate a definition that will describe the functions of the engineer of to-day and of the future, we shall, at any rate, realize and understand better what is the range, what are the kinds, and what is the character of the work which it is the business of the engineer to perform for his fellow-men.

Passing by the pyramids and the works of the Egyptians and of the Eastern nations, it will be worth our while to consider for a short time what was the character of the engineering work of ancient Rome. And, although the development of such work was very different at different periods of the long centuries during which Rome held her sway over the Old World, it will not be necessary for me to trace its various phases, for, inasmuch as the steam engine had not yet been thought of, it was not possible for advances

to be made at such a rapid rate as that with which they are developed in our own times. Moreover, a consideration of the engineering work of ancient Rome gives us a conception of that of the whole civilized world as it then existed; for Rome carried her civilization and her engineering everywhere in the wake of her victorious arms.

Indeed, it was very largely to this cause that was due the firm grip that she acquired over the nations that she conquered. They found that their conquerors offered them a civilization more attractive than their own, and that Rome really took an interest in developing their countries, making good roads connecting them with herself, and sending her own engineers to aid them in making other roads and local improvements, besides encouraging them to develop their natural resources. The intimate connection into which they were thus brought with her led them to introduce such improvements as they found that the Romans possessed. Hence we find that Roman roads, Roman bridges, Roman aqueducts and Roman sewers spread to all parts of Europe, and to all countries which came under her domination. Then when the days of corruption came and when she no longer chose to keep herself in the rank of the producers of the world, but sought to be fed by others without making any adequate return; when she no longer took pains to do thorough work, the Roman example of former times, which had already permeated the other countries of the Empire, still exercised its influence; and hence it is that some of the most lasting and best examples of Roman works were to be found in Gaul, in Spain and in Africa.

When we stop to consider how they managed to accomplish works of such magnitude and of such merit as they did with the small amount of facilities that they possessed, it seems truly wonderful. Imagine for a moment what would be the aspect of the world, and what the material welfare of our own land, if we were to annihilate the use of steam and of all the machinery that depends on steam engines to operate it.

And yet the Romans handled and transported enormous

weights, which would even make us stop to consider how best to handle them.

When they had to carry some of their enormous monoliths long distances over land, they encased them in cylindrical wooden boxes, and rolled these boxes along the ground, drawing them by means of a very large number of horses; then, for lifting them, the means they possessed were tackle, rollers, screws and wedges.

Their stone-cutting had to be performed by manual labor, the use of fire and vinegar being only applicable to certain kinds of stone, and even then being hardly ever employed, and no other blasting compounds being known at that time. On their roads, however, were often to be found large numbers of tunnels cut wholly or partially through solid rock; some of their tunnels were of great length, as, for instance, the two tunnels at Posilipo, and also the emissary of Lake Fucino, the latter being a wonderful piece of engineering considering the facilities that they could command, notwithstanding its failure to accomplish its object. Moreover, they often went so far as to dress the stone on the sides of their tunnels.

The Roman roads I shall not stop to describe, further than to say that, while, from our point of view, they were decidedly narrow, they were built with an amount of solidity that is surprising, and an amount of labor was expended upon them which is very creditable to their makers; moreover, the number and extent of these roads connecting all parts of the Empire with Rome was something enormous for those days.

While they knew and used most of the metals on a small scale, the principal materials employed in their engineering work were stone, bricks and cement, though some of their bridges were built of wood; and of course works of an intentionally temporary character were often constructed of timber.

On account of the difficulties of transportation the materials for building were obtained as near the place where they were to be used as possible; hence, when available, stone was derived from local sources, and this led to the

establishment of quarries at a great many places all over the Empire, the quarrying being performed, however, by manual labor, with a very occasional use of fire and vinegar. For their larger works, their bricks were well burned; but the cost of fuel frequently led them to build houses of bricks dried in the sun. Next, as to cement: whenever they could find suitable materials near by, they used them, otherwise they secured it from further off. They had at Pozzuoli, near Naples, however, the source of supply whence they obtained their famous puzzolana, and this was sent wherever needed, being transported by water to the nearest point accessible by that means, and thence by land.

The Roman bridges and viaducts were either of wood or stone. In the case of the latter the full centre arch was almost exclusively used. When they could locate the foundations of their stone bridges on dry land, they built good and solid structures; but when they had to lay their foundations under water, they always had difficulty, and these were generally washed away in a short time, notwithstanding the variety of expedients to which they had recourse. Hence we find that there were but few Roman bridges across wide streams, where foundations in the river were necessary, but they had no difficulty in crossing deep and narrow gorges where they could establish solid foundations for their work. They had no means of working under water, or of laying foundations under a considerable depth of water, and when they tried they did not succeed to make them sufficiently secure. Their aqueducts and sewers were fine specimens of engineering, considering the facilities they possessed. The water supply from different sources was kept separate, the purest being used for drinking. Their aqueducts were generally made of masonry or concrete, lined with a mixture of cement and brickdust polished smooth.

They carried these aqueducts across gorges or valleys, on stone bridges or viaducts, sometimes built of two or three rows of arches, one above the other, and this method they preferred to the use of siphons, though they had recourse to siphons at times, and, at times they employed a combination of the two methods. They also used settling

tanks to clarify the water by allowing the impurities to deposit. Besides masonry conduits, they used lead pipes, but they had no pipes that could bear a very heavy pressure. They had no means of pumping, and hence the water had to be brought to the place where it was to be used by gravity. The sewers were, of course, a necessary consequence of the water supply, and these ran at one time under every street in Rome; but after the reconstruction of the streets by Nero, the lines of the streets did not always follow the lines of the sewers, and hence sewers often passed under the houses. The earlier sewers were constructed of cut stone, and so solidly were they built that the Cloaca Maxima can still be seen to-day, although the greater part of it is filled up with earth. The pitch of the sewers was small, however, and hence they were easily choked up. Moreover, a great many cities in different parts of the Empire were provided with systems of water supply and drainage.

Taking up next the ports and the waterways, we find that, their boats being small, the works that they needed, and that they therefore executed, would not look large from our modern point of view; but, considering the times, some of them were magnificent pieces of engineering.

As to ports, when they could they built them in a river, erecting quays of stone or wood. They took advantage of the shelter afforded by natural features, and built protecting breakwaters when they needed them.

When they could reach dry land to build upon they always did so, but when not, they sunk large stones, or cradles filled with masonry, locating them by means of divers, or else they built dikes, and ran in liquid concrete, which, on solidifying, formed, as it were, a solid rock.

They had a great many ports all along the Mediterranean. They had, however, no efficient system of dredging, and their ports were always silting up.

Of course, their navigable rivers formed the natural commercial highways, as indeed they did everywhere before the introduction of railroads; hence, they carried out such improvements as they could, and such as were needed at the