Some Aspects of Chinese Engineering

By E. HARRISON KING, JR.

CHINA is a country that was coexistent with ancient Egypt. But, unlike the latter, she has had an unbroken history right up to the present. She has been in a position to be a spectator of the rise and fall of the mighty empires of the earth. She has been strong, and she has been weak, but never dead. Today she is again on the way to greatness.

To such a country all the problems that beset a nation have come, and gone, and come again. And the greatest of these problems, and the most persistent, has been that of maintaining the lives of her people and the life of the nation.

The people as individuals require food, clothing, and habitation. The country, to be properly administered, requires facilities for transportation, protective measures against the forces of nature and of man, and a means of ministering to the needs of the people.

The actual satisfaction of their requirements, as in all countries, has demanded industry and engineering. In China the development of these two activities would make a long, long story, covering many thousands of years; too long to be contained in a few books. But it may be interesting to look at some of the more prominent phases of these two types of human endeavor in order to see how they have developed in the past and what changes have come about in the last several decades.

Even a brief glance at the country discloses one or two salient points: (1) the part that the production of food plays in the life of this densely populated country, and (2) the part that water plays in the production and the transportation of the food. Aside from the construction of habitations and temples and protective walls for cities, by far the larger part of Chinese engineering effort has been devoted to the control and distribution of water and its use for transportation. To obtain water at points remote from streams, wells and pits were dug to get water stored in the earth, and canals were constructed to bring water from distant streams and rivers.

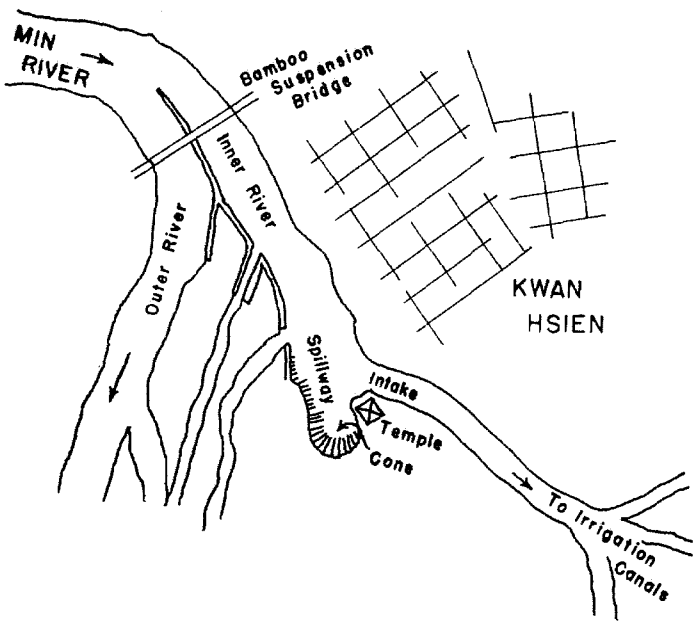

FIG. 1. Plan of Min River Control Works in Szechuan.

To distribute the water where it was most needed, ingenious pumps, operated by man, animal, wind, and water power, were invented, and irrigation ditches and sluices with measuring devices were contrived. Even special water carts and wheelbarrows were designed.

To protect the inhabited districts against the ravages of the great rivers in time of flood, dikes, sluices, and spillways were built.

The construction of so many waterways necessarily interfered with the convenient moving about of the people; so bridges were built to span the watercourses, both artificial and natural.

As more goods could be transported more easily by water than by land, rafts and boats of every description, except those that are self-propelled, were invented, and the amount of thought and ingenuity that went into this phase of engineering will never be known.

Now what has been said above applies to many of the nations of the earth, but through catastrophes caused by nature and by man the results and records of mankind's battle for existence have been lost. The story of China's life is unique in that it has survived through all these years, and because of the peculiar situation of China, geographically, we can see in more or less full flower today those things of which only faint indications remain in other lands. Life ancient, medieval, and modern, can be seen in different parts of China today, each going its practical, untrammeled way. In the older, untouched parts there will probably be only a line or two of telegraph or electric wire to indicate that there is any connection whatsoever with the world as we know it.

Just as an example of what can be found, the author may mention his regular visit at the Chinese New Year, for the past 15 years, to the city of Taichow, just 150 miles from Shanghai, about 40 miles from Nanking, and 17 miles from the Yang-tse River. It has a population of over 130,000, yet, until 1937, there was no road into or out of that city. One reached it through a canal that ended in the moat around the city wall. The only indication of intercourse with the outer world was in the two or three telegraph wires and a few electric light wires. And this was quite a wealthy city, whose leading men had done some traveling.

FLOOD CONTROL AND IRRIGATION

"*To return to our muttons.*" The methods of production of food have followed closely along the lines of all ancient peoples, but the Chinese have applied some interesting engineering thought to the saving of labor, especially in handling irrigation water, from special low head pumps from streams, which are very efficient, to differential axle lifts for wells, bamboo pipe lines, and methods of terracing rice fields in hilly country to conserve soil and water. In connection with this enterprise the Min River Control Works in Szechuan are worthy of mention; these protect the great Cheng-tu Plain.

The Min River has a drainage area above the intake of the control works at Kwan Hsien of nearly 8,000 square miles. Its discharge during flood seasons is often more than 100,000 cubic feet per second. The water from the intake is conducted to a great network of canals

over the Cheng-tu Plain which feed the nearly 1,000,000 acres of rice fields.

Where the river comes from the mountains (see *Fig. 1*), it is divided just above the town of Kwan Hsien into two practically equal channels by an artificial dike or embankment made of cobblestones and gravel, and protected or faced by cobble-filled "sausages," that is, long network tubes of bamboo filled with large rounded stones.

The western channel or Outer River continues in its natural bed until it joins the Yang-tse River. The eastern channel flows down by the town to the intake and the spillway. The intake is a narrow channel cut at an angle with the Inner River by Li Ping through a rocky point to lead the water to a series of canals in the plain to the south and east of the town. This channel was cut quite deep and is so arranged as to prevent excessive flow into it during flood periods.

The spillway is the terminus of the Inner River. It is constructed of sloping banks so that the end of the channel is much like the inside of half a cone with the axis vertical and the apex down. The outer bank leading to this cone, as well as that of the cone itself, is protected by the long rock-filled bamboo baskets or "sausages" mentioned above.

This spillway in time of flood causes the water to rotate in a great eddy, so that before the surface of the stream itself rises above the banks, the centrifugal force throws the outer water of the eddy over the edges of the cone and down to the bed of the outer river, where it can flow away without endangering the rice fields of the plain by overflowing its banks.

Since the river channels may become choked with the sand, gravel, and boulders brought down in flood times, Li Ping made provision for the proper clearing of the channels of the Inner and Outer Rivers at low water seasons by connecting the central dike with one or the other of the main river banks by temporary dikes, thus deflecting all of the water into one channel. The other channel was then thoroughly cleared out to its proper depth. The proper depth was indicated by the exposure of two great pieces of iron which had been placed at the correct depth in the beginning. After one channel had been cleaned, the connecting dike was moved over to the other bank and the second channel was likewise cleaned out.

In order that this cleaning and maintenance should not be neglected over the years, Li Ping built a temple at the junction of the spillway and the intake and put the control of the waters in the hands of the priests, who have continued to make an annual religious ceremony and festival of the work ever since. This has been in operation continuously since its construction under the direction of Li Ping in 250 B.C. No flood or famine has occurred there in that time. It is one of the most remarkable engineering structures in the world.

CONSTRUCTIONAL MATERIALS

In China the "monuments of the past" are rarely the great stone or rock-hewn structures of other civilizations, such as the Egyptian, Greek, or Roman. They are of "earthy" materials and wood, with only a small amount of stone-work for ornament, or where special strength or wearing surface is required. Yet these structures are the work of a cultured, artistic, and civilized people.

The walls of cities, the permanent places, are made of blocks of dried or burned clay, filled in behind with well-tamped earth. In fact, the Chinese character for a walled city (and also for the wall itself) is the character for *complete* with the *earth* radical added. Surrounded by these city walls are temples, palaces, and mansions so well made of "mud," lime, bamboo, timber, and baked clay tile, that they rank as habitations of man on a par with the best of the West.

FIG. 2. Stone and timber construction.

FIG. 3. Single arch stone bridge at Soochow.

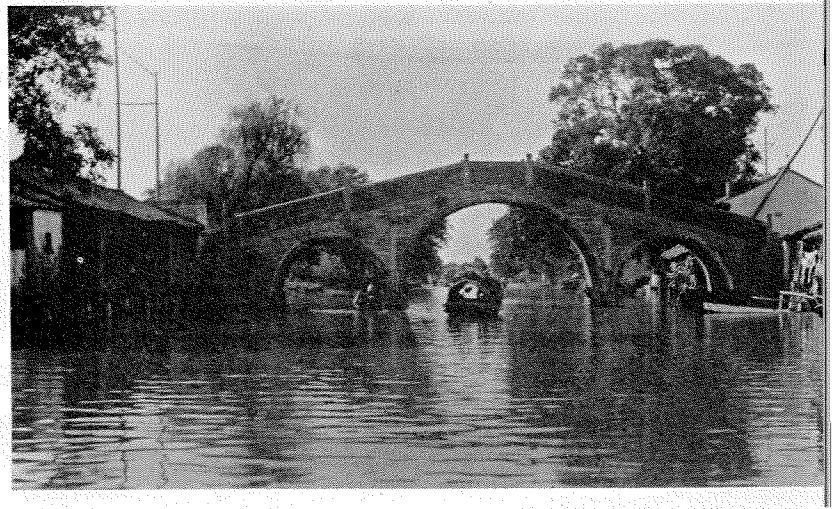

FIG. 4. Triple arch stone bridge at Soochow.

It might be mentioned here that, except in the more rocky and mountainous districts, the use of stone as a

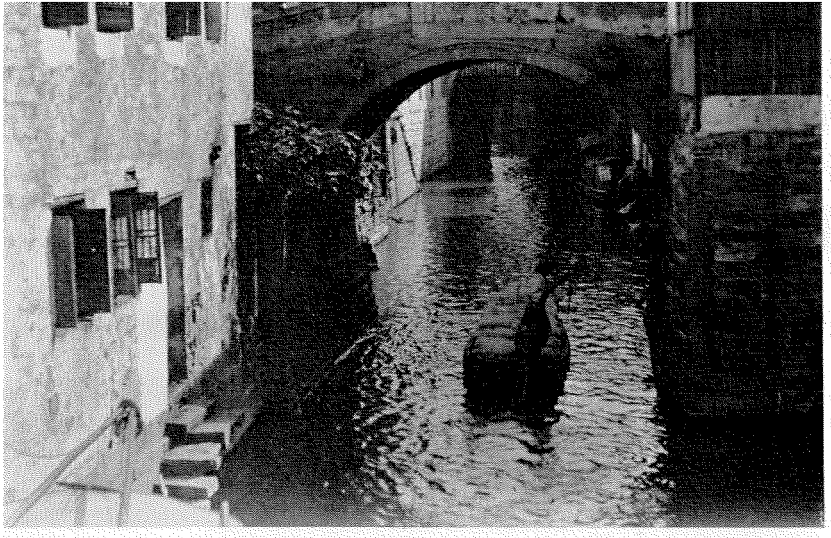

FIG. 5. Stone bridge over canal.

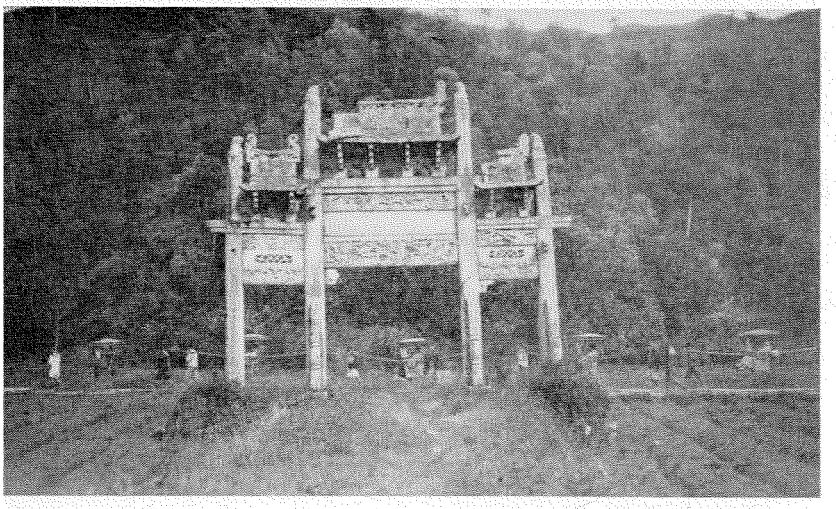

FIG. 6. An old pai-lou or memorial gateway.

major engineering material in China is virtually confined to work in contact with running water, such as bridges, dock and sluice walls, and the facing of some of the dikes. Earth in some form (dried, baked, or as pottery or earthenware), timber, bamboo, and straw are the common building materials throughout the greater part of this vast country. These materials are not the most durable and lasting, yet the Chinese have devised such ways of preparation and construction that structures made of them have lasted several hundred years.

The Great Wall of China itself and the much larger (in section) city wall of Peking are constructed of large clay and clay-lime bricks or blocks, usually six to 10 times the size of ordinary building bricks, or like our concrete blocks, and probably more durable under some atmospheric conditions.

In the Hang-chow area house and garden walls are constructed of tamped earth by means of movable forms that can be raised as the wall goes up, a method almost identical with that used in our modern chimney or high dam construction. These walls are even "reinforced" in a way by horizontal layers of burned tile about a foot apart vertically. Stone or timber is introduced into the construction (see *Fig. 2*) where beams, columns, or wearing surfaces are needed. The roofs are covered with burned clay tile, glazed or unglazed, depending on the wealth or position of the owner. Furniture and decorations of finer quality pottery and porcelain are a further addition, as desired. The walls both inside and out are usually plastered with some mixture of earth, lime, and chopped straw or fiber, and then color washed; in the better buildings they are quite weatherproof.

Stone, as mentioned above, is more in evidence in the construction of bridges (see *Figs. 3, 4, and 5*), dike facings at points where water flows rapidly, and *pai-lous* or memorial gateways (see *Fig. 6*). The bridges and *pai-lous* are often decorated with beautiful and intricate carving. The bridges are of several designs, from the great stone beams or slabs (each about one and one-half feet by two feet by eighteen feet in size), supported by thick stone columns, to lovely single and multiple arch bridges, some of over 50 spans. The famous "camel back" single arch bridges are very beautiful. The construction of the various types of stone arch bridges was carefully specified as to the various details. One of the associations of Chinese architects has studied and preserved the design details of many types of stone and marble bridges in publications put out by the commercial press of Shanghai. Some of these designs show very careful fitting together with keys and dowels of iron.

Timber and wood construction reached a high state of development, as can be seen in the wheelbarrows, carts, furniture, roofs of palaces and temples, and especially in the boats. Whether by simple observation or careful deduction the results of the people's handicraft, both in form and operation, show a very thorough acquaintance with mechanical principles and all phenomena of the forces of nature.

The structural details of the roof frames of the great temples, palaces, and city gate towers are fine examples of strength and beautiful design. In many districts where stone is not available timber bridges of planks on floor beams, supported by long timber piles and bents, similar to our own are used; the traveled way is usually covered with a layer of earth to act as a cushion or shock absorber. In other places suspension bridges of bamboo have been and are still used.

CHINESE BOAT DESIGN

Probably the most scientific and technical use of wood has been in the construction of the Chinese boats. From sea-going junks, or the great boats used on the large, swift-flowing rivers, to the smallest slipper boat and tender the most suitable and practical design has been carefully worked out. These vessels can weather the worst typhoon of the Pacific, with almost no attention from the crew, or make their way through the swift currents and rocky gorges of the great rivers of Asia, of which there are no counterparts. On the other hand they can be handled under many circumstances by old women and boys. A Scottish naval architect has said that they are the most perfectly designed boats in the world.

The ease of handling these vessels is due to many ingenious fittings. To mention just a few: special masts and sails for sea-going craft; high narrow sails for boats used on narrow canals and rivers (see *Fig. 7*), with sheets divided into many strands to obtain every ounce of pull from the wind, and bamboo strips or battens attached to the sails so that they can be raised or lowered quickly, much like a Venetian blind, not requiring to be gathered up and furled by hand; the hinged mast which can be folded down on deck in order to pass under low bridges; the capstan; the long sculling oar which is so bent that sculling the boat is almost automatic; the balanced rudder which requires a minimum of effort; long boats made in two parts and

†See *National Geographic Magazine*, September, 1944, p. 336.

hinged together so that they can be bent to go around sharp curves in narrow canals; warped boats† and also boats straight on one side and streamlined on the other for use under special conditions.

For the preservation of the wood and timber the Chinese have devised excellent waterproof varnishes of tung oil and the famous Ningpo varnish or lacquer, which must be applied in warm damp weather, else it remains sticky forever. The former, together with a lime and tung oil caulking paste, is applied to the hoats used by the guilds for transporting rice and silk so that the transportation of the cargoes in good condition can be guaranteed. The Ningpo varnish can be applied to all woods but is usually applied to Fukien pine, one of the poorest and most porous of woods. This wood is used for making washtubs, water and slop pails, and babies' birth and washtubs. When the utensil is finished, a paste of some reddish earth and oil is worked into the pores, and when this is dry, the Ningpo varnish is applied, which gives a fine waterproof glaze like porcelain, perfectly resistant alike to boiling water and various acids and caustics that would seriously injure other wood finishes.

TRANSPORTATION

The transportation problem is omnipresent, for the people are always moving about and for centuries goods from distant places have come into every district and local products of many special districts have been sent out to the distant borders of the country. When one considers that China has had all sorts of transportation problems, affecting everything that it is possible to transport (barring steam and electricity), it is easy to imagine that many remarkable methods have been devised to suit the conditions. It is true that the people's methods are not always mechanically efficient, but they are usually economically so, and usually sufficient for the purposes and conditions existing.

Water-borne traffic is found wherever water can be used for it. The distribution of the night soil of the country, a very big industry, is water-borne in two ways. In one case it is much diluted with water, then loaded into small tank boats and transported by water

*See *National Geographic Magazine*, September, 1944, for some good illustrations of engineering structures associated with the great salt industry, a government monopoly.

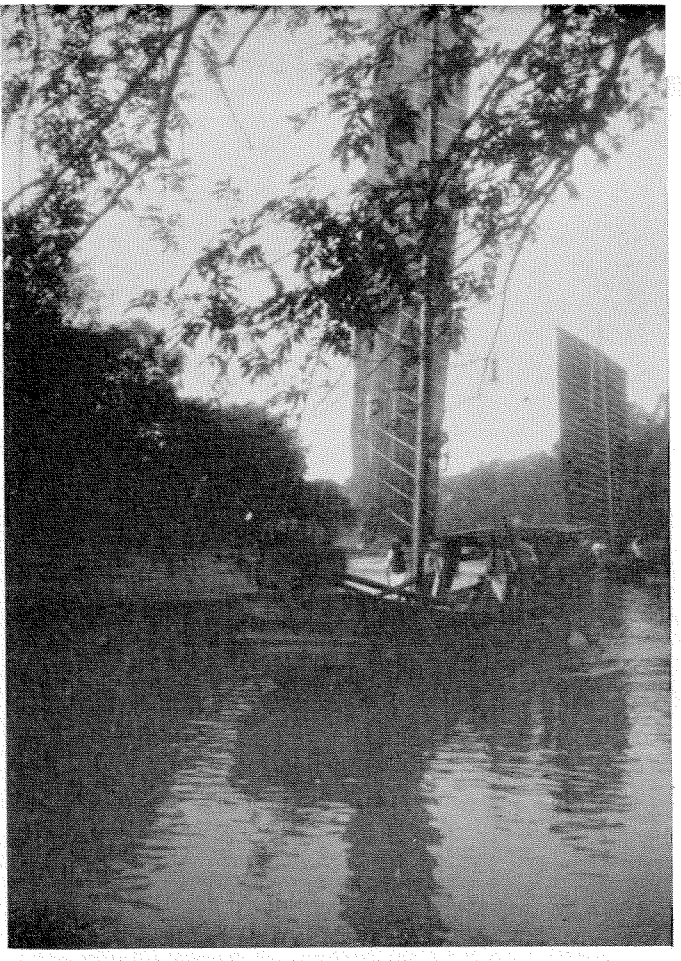

FIG. 7. Canal boats with high narrow sails on Soochow Creek.

to the farmer's fields. Also pipe lines of bamboo, wrapped with narrow bamboo strips, have been used for ages to convey water and transport the brine from the salt wells.*

Probably next in importance is transportation by human beings, one man with a bar on his shoulders and two balancing loads, and two men with one bar over

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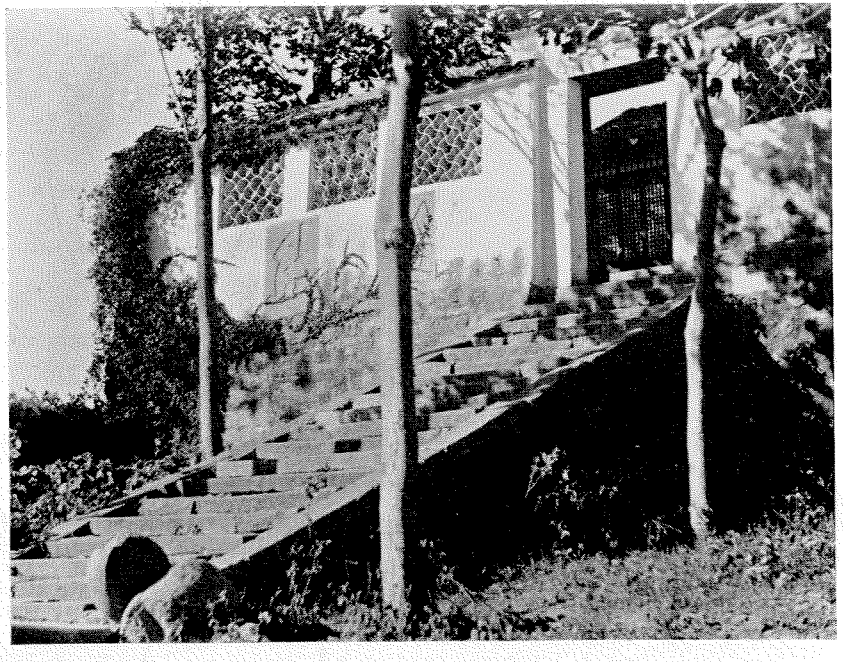

AT LEFT:

FIG. 8. Oblong slabs of granite used for pavements and steps.

Chinese Engineering

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their shoulders and the load between: this last method can be multiplied so that one large heavy load can be carried by as many as 50 men using a composite arrangement of their shoulder bars. Then come various wheelbarrow and cart methods, using men and also animals as the motive power. These last are the least efficient in many ways and the most destructive to the roads, as the barrow and cart tires, being made narrow and concave like a shallow pulley, cut into the earth-road surface and literally chew it up, making deep ruts and hollows. The explanation given for the use of such tires is that they made it easier for the vehicle to climb out of deep ruts and gutters than a flat tire. For that reason many of the roads and cartways of the northern and western plains of China are literally deep trenches which become veritable canals in the rainy season. When they become too deep or muddy, the carters detour at the sides through the farmer's field. To circumvent this practice the farmer digs shallow, grave-like pits or fox holes perpendicular to the road to act as obstacles, thus instituting a sort of economic tank trap.

Usually in the larger towns and near the temples and in the area of the residences and offices of officials the roads are paved with oblong slabs of granite (see *Fig. 8*). This is probably a financial measure rather than an engineering one, as the temples at the various festival times are the centers of big markets and many fees are collected then and at the officials' *yamens;* paving facilitates the easy movement of large crowds, especially in wet weather.

MECHANICAL EQUIPMENT

The foregoing are only a very few examples of the old engineering developments of the Chinese. Contact with Western merchants, manufacturers, seamen, engineers, and others in the treaty ports has brought new and different ideas to their attention. When to their critical minds these new ideas have shown desirable qualities, and if they could be utilized cheaply, the Chinese have not hesitated to adopt them. Before several specimens of their adaptations and adoptions are described, let an instance be given of how some of them came about. One of the large American engineering firms in Shanghai put on quite an exihibit of American machinery and equipment, including even a large tractor-drawn plough, one turn of which would have turned over an average Chinese field. Off in one corner, as a sort of filler to the exhibits, was a small kerosene-driven water pump giving a two-inch or two and one-half-inch stream from a small pool. It was not advertised in any way, but a lot of old farmers were hanging over the railing surrounding it, just looking. Within a very few months the small stock of these pumps (which the writer later learned had been imported for the use of contractors to empty pits and foundation excavations) was exhausted. Another 40 or so were ordered from the United States and these were quickly sold, and another lot of 80 were sold before they arrived in Shanghai. The pump was small, cheap, and used kerosene, a commodity used for lamps and distributed over all of China by the big oil companies. The canny old farmers saw a satisfactory solution to their irrigation problems, since one pump, mounted on a small sled or frame, could be transported anywhere and would serve many farmers.

Secondhand machinery is bought, repaired or altered, and put to some good use. Old steam launches or small tow-boats soon pay for themselves by towing long strings of hand- or wind-propelled boats through the long canals, dropping them off as freight cars are left at sidings in this country, but in this case the "freight cars" can then go where they are required under their own power.

Secondhand electric motors are more and more taking the place of handpower in the many small shops in many of the towns.

One of the most sensible and rapid adoptions is the collecting of old motorcar and truck tires and putting them on the man- and animal-drawn carts. Their use spread like wildfire, for two to four times the former loads could be drawn by about one-half of the men or animals required for the old narrow tires, and these rubber tires helped immeasurably to preserve the roads. Though too far gone to serve on motor vehicles, they would give long service on the soft earth roads at the very slow speed of operation on the carts.

Wealthier and more progressive companies, noting the advantages, began replacing worn-out equipment with new, foreign machines, so that today in the treaty ports and larger cities one may find anything ranging from the ancient method and machine to factories as up to date as many here in the United States. Motor busses and trucks have definitely proved themselves to the Chinese and they are adopted wherever possible. The use of little things, such as watches, fountain pens, kodaks, and the like, has spread to all corners of the country, for not only have the Chinese recognized the convenience of their use, but the possession of such things confers a sort of scholarly distinction on their owners, a very important consideration in China.

The use of concrete, plain and reinforced, has been growing steadily over the last 20 or more years, and one of the good cement mills of the world is located at Shanghai. It is owned by Chinese but is under Swiss supervision and is based on the operations of one of the best of the plants in Switzerland. The raw material, which is excellent for the purpose, is found near by.

In fact, when the demand is great enough, Chinese companies will produce a great many of the things which we produce in the United States. The quality may not be as good to begin with as the quality of our goods, but if the competition is keen enough, and there is still a chance for profit, the quality will be improved. It is doubtful if many very large corporations as we know them will be established for some years, as the family instinct is strong and the desire to keep all profits in the family will act as a deterrent. However, the vicissitudes of the war and the almost complete shake-up in the life of the people may produce unforeseen changes.

The story of the technical accomplishments of the Chinese has come nowhere near being told. Many more will be exposed to Western eyes as the result of the recent influx of outsiders to the old conservative parts of China, where the old methods and tools are still regularly used. If this short sketch serves to arouse even a little interest in the life and lives of the Chinese people, it will have served its purpose.

The eighth Annual Seminar of the Alumni Association will be held on Sunday, April 22. Announcements will be mailed out the first part of the month.