ELEVATORS

DESCRIPTION OF THE LIFTS IN THE EIFFEL TOWER.

BY MR. A. ANSALONI, OF PARIS.

The Eiffel Tower, Fig. 1, Plate 61, though 984 feet high, would be of comparatively little interest if seen only at a distance. The details of this gigantic structure call for close examination; and from its successive platforms, as they rise one above another, a widening prospect is enjoyed, which at the summit extends to a distance of forty or fifty miles round.

In the erection of this work, the designer has also had in view the means of rendering it accessible to the greatest number. To climb 1,800 steps on foot to the summit was not to be thought of, though a staircase may suffice for mounting to the first platform, 189 feet above the ground. This platform can accordingly be reached without fatigue by two wide staircases, constructed in the east and west piers. Even the second platform may also be reached by small winding staircases which occupy the four corners of the tower.

Independently of the staircases however, the ascent is made by means of Lifts arranged in the following manner. Two lifts on the Roux, Combaluzier, and Lepape system, with chains of jointed rods, lift from the ground to the first platform, working alongside the staircases in the east and west piers. Two American lifts on the Otis plan work in the north and south piers, starting likewise from the ground and rising to the second platform at 380 feet height, with option of stopping at the first platform. Lastly, by a lift on the Edoux system, placed vertically in the centre of the tower, visitors are raised from the second platform to the third at a height of 906 feet above the ground.

Each Roux lift is capable of raising 100 persons at a speed of 197 feet per minute, and will make twelve trips per hour; the two lifts together will thus raise 2,400 persons per hour to the first platform, where there are restaurants, cafés, and large covered galleries, whence to enjoy the surrounding views. The two Otis lifts will each hold 50 persons, and work at a speed of 394 feet per minute, and make eight trips an hour, thus conveying 800 persons per hour to the second platform. The Edoux lift will hold from 60 to 70 persons, and make twelve trips per hour, assuming a speed of 177 feet per minute; it will thus raise to the third platform the 800 persons per hour brought up by the American lifts.

ROUX, COMBALUZIER, AND LEPAPE LIFTS. (Plates 62–66.)

These lifts consist essentially of a double chain of jointed rods JJ, Figs. 2 to 4, Plate 62, fitted at each joint with a small pair of wheels, on which the chains run in guide-trunks TT fastened to the inclined girders G that carry the rails R whereon the cabin runs. The rods are 1¾ inches diameter and 3·28 feet long; and jointed together they form a complete circuit, each chain passing at top over a pulley 11½ feet diameter, placed above the first platform. On each side of the cabin is bolted a wrought-iron bar, which forms one link in the chain of jointed rods; and in order to let this attachment pass, each of the two lower guide-trunks has a longitudinal slot S, Fig. 4, all along its inner side facing the cabin; the upper trunk, containing the return half of the chain, is entirely closed. At the bottom, each chain of rods passes under a driving wheel W, Plate 63, 12¾ feet diameter, with twelve arms; on the extremity of each arm is a hollowed steel tooth, by which the eyes of the rods are caught successively, and thus the chain of rods is driven. The driving wheel of each circuit is driven from a hydraulic plunger, 41⅓ inches diameter and 16½ feet stroke, which works horizontally in a hydraulic cylinder 47 inches diameter, Plates 63 and 64. A pair of 63-inch pulleys carried on the plunger head H engage a pair of triple-link pitch-chains N, one end of which is fixed to the cylinder bed-plate, whilst the other end takes half a turn round a double drum D 23½ inches diameter, which is keyed on the shaft of the driving wheel W. For each lift the mechanism is in duplicate; but the driving shafts are coupled together, and the motion is regulated by two water-valves VV, Plate 66, worked simultaneously, by which water is admitted from the reservoirs situated on the second platform, at a height of 380 feet, for raising the lift; while in the descent the water is allowed to exhaust gradually from the cylinders. The water pressure accordingly acts in the ascent only; the descent is made by the weight of the cabin, which is more than sufficient for the purpose, and is partly counterbalanced by lead counterweights placed on some of the rods in the upper or closed guide-trunks.

Balance.—The weight of the two-storey cabin empty is about 14,080 lbs.; the counterweights weigh 6,600 lbs., leaving an unbalanced load of 7,480 lbs., of which the component parallel to the track inclined at $54^\circ\,35'$ is $7{,}480 \times \sin 54^\circ\,35' = 7{,}480 \times 0\cdot815 = 6{,}096$ lbs. This load is sufficient to overcome frictional resistance, as well as to drive the plungers home to the end of the cylinders, and thus enables the cabin to descend empty.

In ascending with 100 persons, estimated at 15,400 lbs., the unbalanced weight of the cabin being 7,480 lbs., there is a total load of 22,880 lbs., representing on the incline a pull of $22{,}880 \times 0\cdot815 = 18{,}647$ lbs. at the extremity of the arms of the driving wheels. On the plungers, according to the ratio of the tackle and without allowing for friction, this pull becomes $18{,}647 \times \frac{12\cdot75 \times 12}{23\cdot5} \times 2 = 18{,}647 \times 13 = 242{,}411$ lbs. Assuming from 45 to 50 feet loss of head in the pipe from the reservoirs on the second platform to the cylinders, there will still remain a pressure of 142 lbs. per square inch on the plungers, or $2 \times 1{,}342$ sq. ins. $\times\ 142 = 381{,}798$ lbs. Of the difference, $381{,}798 - 242{,}411 = 139{,}387$ lbs., about one half will be absorbed in overcoming the various frictional resistances of the lift.

Cabins.—The cabins, Fig. 8, Plate 65, consist of two separate rooms, one above the other, each 8¼ feet high and 10½ feet wide and 13¾ feet long. Each room rests on a wrought-iron floor-frame. By means of slanting cheeks the travelling chains of jointed rods are fastened not only to the sides of the lower room but also to each of the two floor-frames.

Each cabin is carried on four wheels, two on each side, which run on the inclined track. The two rooms are fitted with sliding doors at the sides, which are opened and closed from the outside by the conductor of the lift, who stands on a platform projecting in front of the lower room; or an attendant stationed on the landings minds the doors of the upper room. Each room is fitted with a bench at the back for the whole width, and several short seats; the total accommodation provided is for 100 persons, 30 sitting and 70 standing.

Water Distribution.—The water from the reservoirs on the second platform is brought to the foot of each pier through a wrought-iron pipe about 10 inches diameter. The exhaust water which has passed through the cylinders is returned through another 10-inch pipe to a feed tank which supplies the pumps placed in the south pier, Fig. 47, Plate 77.

The water distributors VV for the two cylinders are placed between the supply and exhaust pipes, Figs. 6 and 7, Plates 64 and 65. Each distributor consists of a cast-iron box with three compartments, Fig. 9, Plate 66, which are separated by two gun-metal valves partially balanced. The valve spindles are worked by two cams M mounted opposite each other on the same shaft, so as to act on one valve or the other according as the shaft is turned one way or the other. The cam shaft is controlled by means of a double rope running along the route of the cabin, so that the conductor can work it at any height for regulating the speed. The cabins are stopped automatically on arriving at either end of the trip by means of tappets A, Plates 63 and 64, which are struck by the heads of the plungers at the extremities of their stroke.

Safety.—Should the chain break at any part, the cabin would simply stop. It could not fall, because the rods forming the chains are constantly abutting against one another; and as the chains are confined in the closed guide-trunks, they cannot buckle under compression. Moreover the mechanism is double, one set on each

ELEVATORS

side of the cabin; and each set is capable of sustaining the whole weight of the cabin, if not of raising it.

OTIS LIFTS. (Plates 67–75.)

The Otis lift is like a tackle acting inversely, the power being applied direct to the movable pulley-block, while the free end of the rope is attached to the load. The power is derived from a hydraulic cylinder H, Fig. 12, Plate 67, 38 inches diameter and 36 feet long, having a piston with two 4¼ inch rods, the upper ends of which are fastened to a truck Y carrying six grooved pulleys of 5 feet diameter. The hydraulic cylinder is shown in section in Fig. 14, Plate 68, the piston with two rods in Figs. 17 and 18, and the travelling pulley-truck in Plate 72. The cylinder is supported on two girders about 131 feet long, inclined at an angle of 61° 20′, as shown in Plates 67 and 68. These girders carry also the path on which the pulley-truck runs; and at their upper end are mounted six stationary pulleys, corresponding with the movable pulleys Y, the whole thus forming a gigantic twelve-purchase tackle. The rope is quadrupled, being composed of four steel-wire ropes of 0·79 inch diameter; the dead end is fastened to the top of the girders by means of a whipple-tree, so as to secure equal tension on each of the four component ropes. The free end of the rope rises above the second platform, being guided by flanged pulleys; the four ropes are then divided into two pairs, which pass down each side of the lift-track and are attached to the safety apparatus beneath the cabin, Fig. 29, Plate 73. In order to diminish the stress on the piston, amounting theoretically to twelve times the load to be lifted, the dead weight is partly balanced by a counterweight T, Fig. 12, leaving only enough unbalanced for enabling the cabin to descend of itself when empty, and to raise thereby the pulley-truck and the piston; the water pressure is admitted into the top only of the hydraulic cylinder, which is thus single-acting. The counterweight consists of a truck 27 feet long, on four wheels, which is loaded with cast-iron weights; it travels upon a track 148 feet long, laid on girders situated directly beneath the lift-track, near the base of the tower, in a straight portion inclined at 54° 35′, Plate 67. It is connected to the cabin by two steel-wire ropes of 0·9 inch diameter, arranged as a three-purchase tackle, and passing over sheaves above the second platform, whence they descend at each side of the lift-track, parallel to the main ropes, and are similarly attached to the safety gear beneath the cabin, Fig. 29.

Balance.—The cabin and its truck, with safety appliances and other gear, make up a weight of 23,900 lbs., which when resolved parallel to the 54° 35′ inclination of the lift-track is reduced to 23,900 × 0·815 = 19,510 lbs. The counterweight of 55,000 lbs. becomes at the same inclination equivalent to 55,000 × 0·815 = 44,970 lbs., capable of balancing 14,660 lbs. on the cabin, after allowing for friction. There remains therefore an unbalanced weight of 19,510 − 14,660 = 4,850 lbs., to which must be added the resultant weight of fifty passengers, say 7,700 lbs. × 0·815 = 6,280 lbs.; and also the dead resistances, together with the increase of load due to the steeper inclination of 78° 9′ in the upper part of the track, say 4,740 lbs. The total resistance is accordingly 4,850 + 6,280 + 4,740 = 15,870 lbs.

The stress on the piston rods will theoretically be twelve times this amount, or 15,870 × 12 = 190,440 lbs. But the weight of the pulley-truck and also that of the piston have to be deducted, representing together about 33,060 lbs. in favour of the power. The height of fall from the level of the reservoirs at the second platform down to the discharge of the water from the cylinder is 393½ feet; allowing for loss of head, and deducting the area of the two piston-rods, a pressure of 156 lbs. per square inch may be taken in the cylinder of 1,134 − 28 = 1,106 square inches net area; and 1,106 × 156 = 172,530 lbs. The total power is therefore 33,060 + 172,530 = 205,590 lbs., which is considerably greater than the power required to balance the total resistance of 190,440 − 33,060 = 157,380 lbs. on the piston.

Cabins.—The cabins, Fig. 11, Plate 67, are nearly identical in dimensions with those of the Roux lifts; and that the two rooms accommodate only 50 persons instead of 100 is in consequence of seats being provided for all the passengers, as a precaution against the tilting movement of the cabin during the journey, owing to the change of inclination of the track, which is 23° 34′ steeper between the first and second platforms. The consequence is that, if the floor of the cabin were horizontal during the lower part of the trip, it would assume a slope of 43½ in 100 during the upper part. To obviate this inconvenience, the floor of the gangway from front to back of each room is formed of steps pivoted on beams, which are adjusted by the conductor to the required inclination by means of a lever. The cabins are so arranged that in their position of mean inclination, namely at the first platform, the fixed floor is practically horizontal, so that the total change of inclination is divided equally and in opposite directions between the lower and the upper portion of the journey. The movable steps being adjusted by the lever to the horizontal position form an actual stairway, downwards or upwards according to the direction of inclination of the cabin. The seats and their backs are rounded, so as to afford suitable support to the body in all positions of the cabin on the inclined track. The conductor's place is under cover, in front of the lower room of the cabin, whence by the handwheel W, Figs. 11 and 26, he can regulate the motion of the lift by means of two ropes working over pulleys, and controlling the lever L of the water distributor, Fig. 19, Plate 69; the controlling gear is shown in Figs. 23 to 26, Plate 71.

Water Distribution.—The two ends of the hydraulic cylinder, Fig. 14, Plate 68, are connected by a circulating pipe C of 9 inches bore, at the bottom of which is placed the water distributor D, shown in Figs. 19 to 22, Plates 69 and 70. For lifting, Fig. 22, the water pressure is admitted into the top end of the cylinder, while at the same time the discharge from the bottom is opened. For lowering, Fig. 21, communication is opened between the top and bottom of the cylinder, so that the pressure has access to both sides of the piston, and the water simply passes from the upper to the under side of the piston through the circulating pipe.

ELEVATORS

When the lift is at rest, Fig. 19, no water is either admitted or allowed to circulate.

The water distribution is effected by means of an upright cylindrical valve-chest 9 inches diameter inside, Plates 69 and 70, in which works a hollow cylindrical slide-valve S, and also on the same spindle a double piston-valve P packed with cupped-leathers. Two pairs of facing ports in the upper part of the valve-chest are controlled by the slide-valve S, and communicate respectively with the pressure supply and through the circulating pipe with the top of the main cylinder. The double piston-valve P controls a lower port, which communicates with the bottom of the main cylinder; and below the piston-valve the bottom of the valve-chest is left open for the discharge of the exhaust water. When the double piston-valve entirely covers the lower port, the slide-valve at the same time covers the upper ports, as shown in Fig. 19; the water cannot circulate, and the lift is stopped from moving. When the valve is raised, Fig. 22, discharge takes place from the bottom of the hydraulic cylinder, while pressure is admitted to the top, and the cabin rises. When the valve is lowered, Fig. 21, the discharge from the bottom is stopped, but the water can circulate more or less freely from the top to the bottom of the hydraulic cylinder through the interior of the hollow slide-valve S; and the descent of the cabin is effected by its weight, which raises the movable-pulley truck as well as the main piston.

The power required to work the valve of the distributor under pressure is about 8,800 lbs.; and to save having to do this by hand, an auxiliary motor is attached to the distributor, Plates 69 and 70, consisting of a piston-valve V 1$\frac{3}{4}$ inch diameter, which applies the water-pressure to an 11-inch piston M fixed on the valve-spindle of the distributor. The auxiliary motor thus controls the distributor, just as the distributor controls the main hydraulic cylinder.

At each end of its journey the cabin is stopped automatically by means of an ear or lip E, Fig. 18, Plate 68, fixed on the piston of the main hydraulic cylinder, whereby the aperture of the port in either end of the cylinder is throttled just as the piston is reaching

ELEVATORS

the end of its stroke. On the top of the piston is a small air-valve A, Fig. 18, which is opened by the pin N (Fig. 13) depressing its tail when the piston reaches the top of its stroke; the air so liberated escapes into the small chamber in the cylinder cover, Fig. 13, whence it is discharged whenever required by opening the air-cock J. To prevent the pair of long piston-rods from sagging, they are made to work through a sliding spider, consisting of a dummy piston U inside the cylinder and a sliding block B above, which are coupled together by a piston-rod of half the length of the main piston-rods, Plate 68; the spider thus travels up and down through half the length of stroke of the working piston, being pushed upwards by the latter and downwards by the movable-pulley truck.

Safety.—It was indispensable with this kind of lift to provide against possible breakage of the ropes. A safety brake with automatic clutches, Plates 73 to 75, has accordingly been applied to the truck carrying the cabin, and also to the counterweight truck, the principle being the same in both cases. On each side of the cabin truck and alongside the rail head are a pair of sliding shoes SS, Fig. 36, facing each other so as to grip the rail head between them; they are carried on a separate lorry L, Figs. 34 and 35, which is hinged at Z to the lower end of the cabin truck, Fig. 11. The shoes are embraced by three separate weights W, of which the two lower are free to slide upon their centre rod; and the shoes are tightened upon the rail head by three wedges working inside the weights. The bottom wedge is single, and thrusts upwards into the underside of the bottom weight; the two upper wedges, intermediate between the weights, are double, each thrusting first downwards into the weight below it and then upwards into the weight above. When out of action, the weights rest on the crossbars of the lorry, while the two upper wedges are withdrawn by springs, and the bottom wedge by the lever V, Fig. 34, which is centred in a lug projecting from the bottom weight; the shoes then run free with 1–8th inch clearance on each side of the rail head.

The six ropes are attached in three pairs, not direct to the cabin truck itself, but to opposite sides of three central rocking plates R, each of which is mounted upon two axes fixed in the framework of the truck, underneath the cabin, as shown in Figs. 29 to 32, Plate 73, and in Fig. 37, Plate 75. Two slots in the plate, forming arcs of circles, allow of its rocking upon either one of the two axes; and when it does so through the breaking of the rope on either side, as shown in Fig. 31, a pin projecting from behind the plate and working in one of the slots in a vertical slide-bar B depresses the bar, thereby depressing also the arm A of a bell-crank lever, Fig. 37, and releasing the catch C which has retained in a state of compression a set of plate-springs pressing downwards on the top of the crossbeam M, Fig. 29. Through the lever V, Figs. 29 and 34, the plate-springs on liberation drive the bottom wedge upwards into the bottom weight, and tighten the shoes upon the rail. The bottom weight and shoes are stopped by the friction; and the descent of the cabin still continuing brings the middle wedge and finally the top wedge into action, each wedge in its turn increasing the pressure of the shoes on the rail. The result is that the cabin is stopped in few seconds. Not only breakage of a rope, but even its mere retching to any unusual extent, is enough to bring the brake into action through this arrangement of rocking plates and connecting gear. After the brake has been in action, the safety apparatus is reset by means of a screw and hand-wheel H, Fig. 37, by which the plate-springs are compressed sufficiently for the catch C to be caught and held up by the bell-crank lever A.

Should all the ropes happen to break simultaneously, as soon as ever the speed of the falling cabin exceeds ten feet per second it will at once bring into action a centrifugal governor, fitted within the wheel K at the top end of each brake lorry, Fig. 11, as shown in Figs. 38 to 41, Plate 75. The two serrated segments GG flying apart with the increasing speed, one or other of their teeth will strike the trigger T, and release the latch D, Fig. 38, thereby liberating the helical spring P, which by means of the slotted rod Q lifts the arm N projecting from the back of the horizontal shaft F; an opposite arm projecting from the front of the shaft depresses the arm A of the bell-crank lever, and thus releases the catch C and liberates the plate-springs, by which the brake is then brought

ELEVATORS

into action as before. In ascending faster than ten feet per second, the backs of the teeth in the centrifugal segments will merely trip the trigger T, which is loose in rising, and therefore does not then act upon the latch D.

The safety apparatus, which has never been used before, has been especially designed for these tower lifts by Mr. T. E. Brown, Jun., engineer-in-chief of Messrs. Otis Brothers and Co., by whom also the construction of the lifts was designed and superintended.

EDOUX LIFT. (Plates 76 and 77.)

The Edoux lift is widely employed in Paris, the most important example hitherto constructed having been erected there in 1878 in one of the towers of the Trocadéro Palace. The cylinder is vertical and about 230 feet long, necessitating the excavation of a deep pit to receive it. For balancing the lift very large ropes are required, inasmuch as they have to be equal in weight to half the volume of water displaced by the piston.

In the lift at the Eiffel tower, between the second and third platforms, both the above inconveniences have been obviated by an ingenious arrangement. Instead of effecting the ascent of 526 feet in a single flight, which would have been difficult to manage and sadly inefficient, the trip has been divided into two equal flights by a midway platform, Fig. 42, Plate 76; and there is one cabin for each flight. The two cabins counterbalance each other, being connected by means of four steel-wire ropes, which pass over pulleys above the third main platform. One cabin travels up and down the lower half of the trip, a height of 263 feet, whilst the other travels through the same distance in the upper half. Travelling in opposite directions, the two cabins thus meet and part at the midway platform, where the passengers brought up by the lower cabin change into the upper cabin, in which they complete their upward trip to the third main platform; while those brought down by the upper cabin change into the lower for descending to the second platform.

ELEVATORS

The two cabins are both guided by one central vertical column extending through the whole 526 feet height of the lift; and also by two smaller columns, each of which is half this height, one rising from the second main platform to the midway platform, and the other from the midway platform to the third main platform. The upper cabin is carried on two hydraulic rams of 12·60 inches diameter, working in cylinders HH of 14·96 inches diameter, Plate 76. To shelter them from the action of the wind, the rams are arranged to work within the upper guiding columns, within which also work the ropes that carry the lower cabin. The cylinders and rams are of steel plate riveted, except a portion of the length of the rams, which is made of cast iron, in order to obtain the extra weight necessary for lifting the suspended cabin with its passengers. The bottoms of the hydraulic cylinders hardly protrude below the floor of the second main platform.

Balance.—The sectional area of each ram is 124 square inches, or 248 square inches for the two; and their weight is 42,330 lbs. Supposing the lower or suspended cabin to be empty and to balance only the dead weight of the upper cabin, and that the latter be loaded with 8,800 lbs. weight of passengers, then in starting from the midway platform the pressure required under the rams to correspond with the unbalanced load should be equal to 42,330 + 8,800 = 51,130 lbs. The water being supplied by a reservoir 526 feet above the bottom of the cylinders gives a pressure of 228 lbs. per square inch at starting. On the combined area of the two rams the total pressure accordingly amounts at starting to 228 × 248 = 56,550 lbs.; and the difference, or 56,550 − 51,130 = 5,420 lbs., represents friction and loss of head. As the rams rise out of the cylinders, their weight increases while the head diminishes; but the balance is maintained by the increasing length of the ropes on the other side.

Safety.—The four ropes weigh together $53\frac{3}{4}$ lbs. per foot, or $53\frac{3}{4} \times 526 = 28{,}270$ lbs. for the total height. Their net sectional area is about $15\frac{1}{2}$ square inches. Taking the weight of the lower cabin full of passengers at 18,740 lbs., the maximum load to be supported by the ropes is 28,270 + 18,740 = 47,010 lbs. or 21 tons, while their aggregate breaking strength is upwards of 500 tons. Hence the apparatus is perfectly safe.

Backman Brake.—In order to dispel all misgivings, the Backman brake, Figs. 43 to 46, Plate 77, will be applied on each side of the suspended cabin. In this plan a drum D turning on a vertical spindle works up and down within each guiding column G of the lower cabin, like a long-pitch screw in its nut, being threaded helically so as to gear with a corresponding helical rib H formed round the inside of the column. Round the drum thread are spaced a set of four rollers R running on the rib, which enable the drum to accompany the cabin up and down with scarcely any resistance. The top of the drum is turned conical, to fit into a corresponding hollow cone C turned in a bracket attached to the cabin. Should the cabin fall, it would quickly overtake the drums, because the latter have to run down their helical paths, while the cabin is falling vertically; the cones then coming into contact would cause friction enough to stop the drums from rotating; and the drums being thus locked in the columns would support the cabin and prevent its falling further.

PUMPS.

Water under pressure is the only motive power combining the precision and the ease of management required for lifts; and accordingly all the Tower lifts are worked by water, which is supplied by pumps placed in the bottom of the south pier, Fig. 47, Plate 77. Those by which the four ground lifts are fed pump the water through a pipe of 9·84 inches diameter into two cylindrical tanks, each 9 feet 10 inches diameter and 23 feet long, placed on the second platform. The two tanks are connected together by a pipe 19·69 inches diameter, from which four branches are led down to supply the cylinders at the foot of each pier. On leaving the cylinders, the water returns through underground pipes into

ELEVATORS

the feed tank at the south pier, whence it is pumped anew into the upper tanks.

The Edoux lift is supplied by two Worthington pumps, which deliver the water into a tank 9·84 feet diameter and 13 feet deep, placed on the third platform, Plate 76. A similar tank on the intermediate platform receives the discharge water, so that the pumps take their water from a height of 656 feet and deliver it to a height of 918 feet. The cast-iron pipes are made extra strong to resist so great a pressure.

WORK DONE AND CONSUMPTION OF WATER.

Each of the Roux lifts consumes 1,925 gallons of water per trip, or the two together 3,850 gallons. Each Otis lift consumes 1,728 gallons per trip, or the two together 3,456 gallons. The four lifts together consume therefore 7,306 gallons in one minute, since each of them takes one minute for the ascent; this is equal to 121·8 gallons per second.

The difference of level between the pumping tank at the south pier and the supply tanks on the second platform is about 443 feet, after adding the loss of head. The power absorbed during the ascent of the four lifts from the ground level is thus equivalent to $\frac{7306 \times 10 \times 443}{33{,}000} = 980 \cdot 7$ horse-power, or say 1,000 horse-power.

The Edoux lift consumes 31·69 gallons per second. The difference of level between the two tanks, adding the loss of head, may be estimated at 393·7 feet, which will give for the power exerted in the ascent $\frac{31 \cdot 69 \times 60 \times 10 \times 393 \cdot 7}{33{,}000} = 227$ horse-power.

The combined power thus amounts to over 1,200 horse-power, which however is in reality exerted only at intervals, namely at the times of the ascents, that is to say for about one-fifth of the time occupied in making the complete trip up and down. The power is accumulating in the tanks during the stoppages and descents, and consequently less than 300 horse-power is required to be developed continuously by the pumps.

The Roux lifts consuming 3,850 gallons of water per trip take for their twelve trips per hour $3{,}850 \times 12 = 46{,}200$ gallons per hour.

The Otis lifts consume 3,456 gallons per trip, or for their eight trips per hour 3,456 × 8 = 27,648 gallons per hour. The total quantity of water required is therefore 73,848 gallons per hour, or 20·5 gallons per second, to feed the four lifts ascending from the ground.

The two pumps furnishing this supply, Fig. 47, Plate 77, each deliver 11 gallons per second at their ordinary speed, and at a higher speed are capable of supplying 18 gallons per second. The steam cylinder employed to work each pump has the Wheelock valve-gear, and is 23·6 inches diameter with a stroke of 3½ feet; it works direct a horizontal double-acting plunger on the Girard plan, 11·4 inches diameter. These engines were constructed at the Quillacq works at Anzin.

The two Worthington pumps for the Edoux lift are driven by two tandem compound cylinders, Fig. 47, Plate 77. Together they supply 9·68 gallons per second at their ordinary speed, corresponding with a consumption of 34,862 gallons per hour. The volume of water required for each ascent is the product of the joint area of the two rams, or 248 square inches or 1·72 square foot, multiplied by the height of the half-lift or 263 feet; it is therefore 453 cubic feet, or 2,825 gallons. The total volume consumed for the twelve ascents made in an hour is therefore only 2,825 × 12 = 33,900 gallons.

A range of four Collet safety boilers is placed underground at the south pier, Fig. 47, Plate 77, near the steam pumps. Each boiler is capable of generating 3,300 pounds of steam per hour at a pressure of 140 lbs. per square inch. Three boilers are sufficient for driving the pumps in full work: the fourth is kept in reserve.

REFERENCES

[BSE] Building Services Engineering (A review of Its Development) Neville S Billington & Brian M Roberts, Pergamon Press, Oxford, 1982.

[ET] The Eiffel Tower: Symbol of an Age, Joseph Harriss, Paul Elek, London, 1976.

[ETL] Eiffel Tower Lifts (Description of the Lifts in the Eiffel Tower), A Ansaloni, *Mechanical Engineers*, London, July, pp. 359-378 & accompanying plates.

[GE] The Great Exhibitions, John Allwood, Studio Vista, London, 1977.

[IA] Icons of Architecture: The 20th Century, Prestel, Munich, c.2000.

[OT] Otis: Giving Rise to the Modern City, Jason Goodwin, Ivan R Dee, Chicago, 2001.