(Paper No. 2177.)

“The Hydraulic Passenger Lifts at the Underground Stations of the Mersey Railway.”¹

By WILLIAM EDMUND RICH, M. Inst. C.E.

A NOVEL feature of the Mersey Railway, is the introduction of large hydraulic lifts for conveying passengers and their luggage, from the deep underground stations at James Street and Hamilton Street, to the daylight stations at the street-level above. In such situations these lifts may be looked upon practically as vertical branch-railways, and as such, a more detailed description of them, and of the apparatus connected with them (Plate 5), than that given in Mr. Francis Fox's Paper on the Mersey Railway Works generally, may be of interest to the Institution.

The rails, which rise with steep gradients in both directions from the centre of the tunnel, reach James Street Station near the Liverpool Exchange, at a depth of 92 feet below the street-level, and at Hamilton Street Station (the nearest to the river on the Birkenhead side) the rails are 103 feet below the street.

The object of the lifts is to relieve passengers making use of these stations of most of the fatigue of walking up and downstairs through the above vertical distances, and to convey them up and down much more quickly than would otherwise be possible.

In each station there are three lifts (Plate 5, Figs. 1, 2, 3), which are worked quite independently of one another, and are each capable of raising one hundred passengers at a time. The average journey is accomplished in from thirty to forty seconds, and the three lifts, working simultaneously, are capable of raising a train load of three hundred passengers to the surface in about a minute. The lifts are of the direct-acting ram type, having hollow steel rams 18 inches in diameter, with balance-chains and counterweights at the sides. The ascending-room, or cage, in each lift is 19 feet 6 inches long, by 16 feet 6 inches wide, and 8 feet to 10 feet high, all inside dimensions, and is constructed with handsomely panelled sides and roof of teak and American ash, with seats for twenty-four passengers along the sides, and a large gas lamp in the centre of the roof.

¹ The discussion upon this Paper was taken together with that upon the preceding one.

The motive-power is water at a low pressure derived partly from a tower-tank holding 10,000 gallons, and partly from steam-pumping engines, discharging direct into the lift supply-pipes.

On the downward journey the water is discharged into the underground waste tank, from which it is pumped back to the upper tank by the engines. The lifts at James Street have a stroke of 76·6 feet, and those at Hamilton Street of 87·7 feet.

In consideration of the greater traffic which may be always expected at James Street, there are three boilers and three sets of pumping engines there, as against two boilers and two sets of engines at Hamilton Street; and the arrangement of this machinery in plan at the two stations is somewhat different; but for the purposes of this Paper it will be sufficient generally to concentrate attention on the detailed arrangements at James Street. The station-buildings there are on the west side of the street. The booking-hall on the ground floor is 46 feet long, 33 feet wide, and 19 feet high. On the south side are entrance doorways to the A and B lifts; and on the north side are doorways leading to the C lift, and a flight of stairs which also leads to the lower hall 76·6 feet beneath (Plate 5, Fig. 1).

The engine-room is intermediate between these two floors, being at a height of 27·2 feet above the lower hall. The remaining space between the engine-room and the booking-hall floors is occupied with floors for luggage, stores, porter's room, &c.

The lower hall is very similar in plan to the booking-hall above having doors similarly placed for access to the lifts and stairs, and in addition an arched opening on the west side forms the entrance to an inclined subway, leading towards the Exchange. On the east side are two open arches about 12 feet wide. The most northerly of these leads by a flight of broad winding steps to the up-line platform at a level of 12 feet 10 inches below the lower hall floor. The other arch gives access to the down platform on the opposite side of the tunnel station by means of a lattice-girder foot-bridge.

The station buildings are carried up to a considerable height above the booking-hall, and will probably be let out in offices, for the convenience of which a small passenger lift is provided. A tower rises above the main block of buildings, and contains at its upper end the top tank, 15 feet 6 inches diameter, 9 feet deep, which holds 10,000 gallons of water. The waste-tank of similar capacity is excavated out of the rock beneath the engine-room floor, and lined with brick in cement.

The several lifts are contained in rectangular vertical shafts,

21 feet long and 19 feet wide, partly excavated out of the solid red sandstone rock, which stands with clean dry vertical surfaces without lining, and partly enclosed in walls of brick in cement, which separate the shafts from one another, and from the engine-room, booking-hall, &c.

Each shaft descends to a depth of 8 feet below the lower-hall floor, and rises to a height of about 20 feet above the upper booking-hall floor. On each side of the shaft four vertical rows of wooden bricks, Figs. 3 (p. 66), are fixed in the walls with thin folding wedges. These bricks are cut out of pine sleepers, of a section 10 inches by 5 inches, and they are let into the walls, and project outwards from the faces of them. They are spaced at 5 feet apart vertically from centre to centre. To these wooden bricks eight lines of rails are attached with coach-screws; four of these rails serve for guiding the cage, and the remaining four for guiding the counterweights. These rails are of steel of the section shown in Figs. 3 (p. 66), and are in 15-foot and 10-foot lengths, connected by fish-plates. They were all specially straightened, and fixed accurately to gauges, so as to form very true guiding surfaces. The advantage of the V-shaped guiding surfaces is that the guide-brackets, which slide over them, can be efficiently adjusted as they wear, by packing them out in one direction only.

In the centre of each lift space, and vertically downwards from beneath its floor, a boring has been carried down to a depth of 75 feet, for receiving the lift-cylinders. The three borings, at Hamilton Street, were constructed by Messrs. Timmins, of Runcorn, with the old-fashioned jumping tackle, and they are about 35 inches inside diameter and 86 feet deep. Those at James Street were constructed by Messrs. Mather and Platt, with their well-known boring-tackle, with large boring heads specially constructed for the purpose; these borings are 40 inches diameter.

It is interesting to note that Messrs. Mather and Platt's tackle was much more elaborate than that of Messrs. Timmins, and many weeks were occupied in getting it rigged ready to start; but when once started, the rate of progress was more than twice as fast, and the work was more accurate, as regards verticality. It is of the utmost consequence that the cylinders of hydraulic lifts should stand truly vertically, and hence it is essential that the borings for receiving them must be as nearly plumb as possible, and sufficient extra diameter beyond that of the cylinder-flanges must be given to the boring, to provide for its possible lack of verticality. In London the Author has of late years adopted wells, 3 feet in internal diameter, for receiving lift cylinders, in

preference to borings, which give great trouble when they are out of plumb.

The cast-iron lift-cylinders are 21 inches in internal diameter, and $1\frac{1}{8}$ inch thick, with strongly bracketed flanges, 29 inches in diameter, and they are bolted together in 12-foot lengths, with sixteen bolts $1\frac{1}{8}$ inch in diameter to each joint, and suspended in the boring from the top length, which is furnished with a large bell-foot, 4 feet 8 inches in diameter, which rests on the floor of the lift space. This top length also has a tee-branch on the front side, for connecting it with the starting-valve, and at its top end it is bored out 18 inches in diameter, and fitted with a hat-shaped leather for making the joint round the ram. The ram, which descends into the cylinder, is 18-inches outside diameter, and $\frac{1}{2}$ inch finished thickness, constructed of mild steel tubes, in lengths of about 11 feet 6 inches. These tubes are turned and polished, and connected together by internal screwed ferrules, 6 inches long, and $15\frac{3}{4}$ inches internal diameter, the screw-threads being eight to the inch. The bottom end of the ram is a tough heavy casting, with hemispherical bottom, and as an additional security, rods, $1\frac{1}{2}$ inch in diameter at the smallest part, are attached to this bottom casting, and carried up the centre of the ram, so as to securely grasp the boss of the main cage-cross at its top end.

The tubes for these rams were forged by Messrs. James Russell and Co., of Wednesbury, from Landore-Siemens steel plates, $\frac{3}{4}$ inch thick. They were lap-welded in short lengths of a few inches at a time under a hydraulic press. The steel was tested by Professor Kennedy, and was found to break with a load of 63,000 lbs. per square inch, the average extension being about 29 per cent., and the contraction at the point of fracture 47 per cent. The ram preserves its uniform diameter of 18 inches to its top end, and there enters the boss of the steel cage-cross, and is attached to it with four $1\frac{1}{4}$ -inch turned bolts with nuts and guard-pins.

The cage-crosses, which are shown in Figs. 2 (p. 64), were forged by Messrs. Clay, Inman and Co., of the Birkenhead Forge, and are considered very fine specimens of complicated steel forgings. Each cross in its finished state weighs $21\frac{1}{2}$ cwt., and was forged out of an ingot weighing originally about 3.4 tons, supplied by the Steel Company of Scotland. Mr. Salmon, the managing director of the Birkenhead Forge Company, has furnished the Author with the outlines of the successive stages by which these crosses were forged (Figs. 2). He made a great point of discarding as a matter of course several inches of the original ingot near its top end, and before anything was done

the side surfaces of the ingot were carefully examined, and any

FIGS. 2.

parts showing a spongy texture or surface cracks were cut away by milling or slotting machines. In the first place the ingot was

drawn out under the hammer, and dented at *a a*. Secondly, the holes *b c c* were drilled, and the pieces *d d* slotted out; next the arms were drawn out straight to their full length; then the boss was bored, and its outside edges and the junctions of the arms with it were neatly slotted round. Finally the arms were bent away to form the feet, and the faces of these feet were planed off to gauge. Each cross measures 9 feet $6\frac{1}{4}$ inches wide over the feet, and 11 feet long, and the boss is 15 inches deep and 2 inches thick. The arms are 2 inches thick near the boss, and $1\frac{1}{4}$ inch thick, and 11 inches deep at their outer ends. The cross is riveted by means of the four feet at the ends of its arms to the vertical webs of two thick English rolled joists of H-section, 18 feet 8 inches long, 14 inches deep, and 6 inches wide; and these girders are further strengthened by riveting on to their top and bottom flanges iron plates, 12 inches wide, $\frac{1}{2}$ inch thick.

These foundation girders are laid transversely beneath the lift-cages and are extended beyond their sides, to enable the counter-balance chains to be attached at their outer ends. The floor of the cage or ascending-room consists of eight pitch-pine joists, $10\frac{1}{2}$ inches deep, those at the sides being $5\frac{1}{2}$ inches thick, and the others $3\frac{3}{4}$ inches thick. Each of these is attached to the top plates of the main girders mentioned above by four stirrups of $\frac{3}{4}$ -inch iron, screwed at the ends, and fitted with nuts beneath the flanges. At the front and the back of the cage these wooden joists are morticed into transverse timbers of the same depth as themselves, and $5\frac{1}{2}$ inches thick. A teak floor, $1\frac{1}{4}$ inch thick, is laid on this timber framing, and the sides and ends of the cage formed of teak frames, 3 inches thick, with American ash panels, $\frac{3}{4}$ inch thick, are built upon it.

The roof of the cage is also panelled, with looking-glasses in the inclined panels to reflect the light of the central gas-lamp downwards. For a width of 2 feet round the sides the roof is of extra strength, having double boarding, so as to form a good gang-way for inspection of and access to the working gear, and to support any loads which it may be convenient to lay upon them, in the case of overhauls or replacing chains, &c. There are spline seats on each side of the cage, and on the front side is the doorway, 4 feet wide, with sliding-door fitted with clear glass panels.

The ornamental panel-work was designed by Mr. Grayson, of Liverpool, the Architect for the station buildings, and the wood-work of the cages was constructed by the Starbuck Car Company, of Birkenhead.

The cage is kept in position, and guided from top to bottom of its stroke, by four cast-iron **V** guide brackets, 16 inches long, bolted to the flat sides of the vertical webs of the girders at their ends, and adjusted with wooden packings, so as to bear on the four steel rails above mentioned (Figs. 3). They can be easily removed, and thicker packings added as they wear away.

Above the lift-cage, at the top of its stroke, two Butterley rolled-joists, 16 inches deep and $5\frac{1}{2}$ inches wide, span the lift-space cross-wise, and on the ends of these, at a distance of 5 inches from the

walls, two other joists of the same section are seated and securely bolted to them. From each of these side girders two chain pulleys, 4 feet 8 inches in diameter, are suspended by means of stirrups of forged plate-steel, with central turned bolts, 3 inches in diameter, furnished with trebly-secured attachments at their ends.

Between each pair of pulleys a counterweight is suspended by two $1\frac{1}{8}$ -inch short link chains, with an eyebolt and double nuts at one end of each, for attaching it to the weight.

Each main weight weighs 7,620 lbs., and is fitted with recesses for receiving thirty-nine or any smaller number of weights of

90 lbs. each for balancing the lift; these may be very easily put on or removed by an attendant on the cage top.

The chains pass over the pulleys above-mentioned, and are attached by long U-shaped shackles and cotters (Figs. 4), to the ends of the cage girders.

It is noteworthy that no ordinary shackle will pass through the links of short-link chain. With these, however, a chain can be cut anywhere, and attached more securely than with common shackles, which the Author considers weak and unreliable devices for such responsible duties. The lift starting-valve is placed on the bottom floor of the lift space, vertically, beneath the cage

FIGS. 4.

door; it consists of a gun-metal slide-valve, working on a cast-iron face. The supply port is shaped so as to enable the valve to be closed and opened without causing sudden shocks in the water, and through it to the lift-ram. The valve is actuated by a pinion working into the teeth of a rack cast on the back of the slide. The pinion is cast in one with the spindle, which passes through two stuffing-boxes in the sides of the cover, with a 4-foot rope-wheel on one end of it.

A hempen hand-rope, with wire-rope core, is attached at its two ends to this wheel, each end lapping three-quarters round it at half-stroke. This rope passes up through the lift-cage, on each

side of the doorway, and over two pulleys fixed at the top of the lift-space. The rope on the right-hand side of the doorway looking out is fitted with stops; so that the lift is arrested as it approaches the top and bottom floors by engagement with these stops, and so closes the valve.

A large self-acting flap-valve admits water automatically to the lift-cylinder from the exhaust, if the starting-valve is closed too suddenly during the ascent of the lift; and as the full stroke of the hand-rope from full pressure to full exhaust is 9 feet, it is found that the lift starts and stops with great quietude and comfort to the passengers. A lock on the hand-rope in the cage prevents any unauthorized person from actuating the starting-valve.

The floor of the engine-room is 27·2 feet above the Lower Hall, and is constructed of wrought-iron girders and Mallet plates, with concrete above them. A safe floor of similar but lighter construction is formed at a depth of 5·9 feet below the engine-room, and serves to give access to the waste-tank and many of the pipes, &c.

The plan of the engine-room at James Street is shown in Plate 5, Fig. 2. There are three boilers and three pairs of pumping-engines, arranged symmetrically, with steam-pipes so placed that any engine, boiler, or pipe can be shut off for repairs without stopping the rest. The boilers are of the return-tube type, each 6 feet 6 inches in diameter, 11 feet long, with a single flue 3·0 feet in diameter, and 3-inch tubes. They are constructed of mild-steel plates, and are loaded to 60 lbs. per square inch on the safety-valves. An iron flue over their front ends conveys their waste gases to the chimney in the corner of the engine-room.

The pumping-engines (Figs. 5) are of the duplex type, each with two steam-jacketed cylinders 11 inches in diameter, and 20 inches length of stroke, working direct off their piston-rods, two double-acting piston pumps $7\frac{1}{2}$ inches in diameter, and 20 inches length of stroke. The slide-valve of each cylinder is worked by a lever from the piston-rod of the other, so that there are no dead centres, and they are so arranged that the pistons cannot strike the cylinder ends. So long as the gross pressure on each steam-piston exceeds the resistance against the pump-piston, due to the water-pressure against it, together with the friction of the working parts, these engines will keep working, pumping water from the waste tank into the system of pipes, which connects the top tank with the lifts. Any reduction of pressure in the pumps increases the speed; but immediately the above pressures and resistances are equalized, either by closing a valve on the delivery side of the

pumps, or in any other way, the engines stop "dead." They

FIGS. 5.

start again, however, automatically at full speed, directly the

resistance to the pump action is relieved by opening the valve or otherwise, even though they may have been standing for hours in the interval. The valve or other resistance may be any distance, even miles off. As there is very little inertia in the working parts, the pressure against the pumps may be put on or taken off with the greatest rapidity without injury to anything.

Engines of this type have been used by Messrs. Easton and Anderson, M.M. Inst. C.E., during the last twenty-five years for a great variety of purposes, such as waterworks with and without reservoirs, naphtha-pumping through long mains, working lifts, hydraulic presses, riveting-plant and gun-carriages, and as bilge-pumps and fire-engines on board ship. Their details and proportions have been considerably varied and improved by "natural selection," as a matter of course, in the interval, but the original principle remains.

Each set of engines at the Mersey works is proportioned to give a hydraulic pressure of about 1.6 time the boiler pressure when discharging 500 gallons per minute, rising to 1.9 time that pressure when working "dead slow." Pending the completion of the tower for receiving the top tank, the several lifts at James Street have been worked so far direct from these engines without any supply tank. The steam stop-valves on the engines are left wide open from morning to night, and their action is entirely controlled by the lift starting-valves. There is an air-vessel on each set of pumps, and a small one on each lift-valve, and these suffice to neutralize all irregularity of flow, so that no pulsations are noticeable in the lifts.

At Hamilton Street the tank and engines are now in full working order, and jointly supplying the lifts.

The normal duty of the engines is to automatically keep the top tank full, and to assist it to work any lift whose starting-valve is open for ascending. In case of an excessive load beyond the powers of the tank-pressure to deal with, the engines immediately take the entire duty of raising the lift so loaded.

The system of main-pipes and of change-valves between the tanks, pumps, and lifts, is shown in skeleton in Plate 5, Fig. 1. Three 7-inch mains descend from the tank-bottom to the several lifts, one to each.

Beneath the tank these pipes have sluice-cocks, A A A, and self-acting valves, B B B, which prevent flow through them towards the tank. Branches beyond these lead to ball-valves, C C C, for supplying the tank and shutting off the water when it is full.

In the engine-room multiple crosses are introduced in these mains, with branches to the pumps and connections between the several main pipes, and eleven 7-inch sluice-cocks so arranged that the engineer in charge can readily shut off any tank-main with the cocks D D D, or any pump with the cocks E E E, or any lift with the cocks F F F, still leaving everything else at work. With the cocks G G on the junction pipes he can cut off the connection between the mains, leaving each lift-system complete in itself, with its own tank main and pumping engine. In normal working, however, it is best to leave them and all the other cocks fully open, as each lift then gets the benefit of all three supply mains and all the pumping-engines which may be under steam at the time. There is no doubt that the concentration of these change cocks and mains, in accessible positions, and in a symmetrical and intelligible order, will prevent many mistakes on the part of the attendants.

The above pumping engines work at high pressure, and discharge their exhaust steam through a feed-water heater into the chimney. Donkey-engines of the small duplex type are to be added shortly, and short-stroke unbalanced ram-lifts are to be fixed on the platforms for raising luggage to the foot-bridges, from which the trolleys can be easily wheeled into the large lifts. Small hydraulic ash lifts for raising the ashes produced in the engine-room are also in contemplation. All will be worked from the same system of mains in the engine-room.

The office passenger-lift is of the type generally adopted by Messrs. Easton and Anderson, with a $7\frac{1}{2}$ -inch wrought-iron ram $\frac{3}{8}$ -inch thick, a forged-iron cross at its top end, a steel-plated cage with domed steel-plate roof, and a heavy chain and counterweight. The roof of this lift-cage will be serviceable for giving access to the pipes from the tank which pass down the lift-space beside it to the engine-room below.

GENERAL REMARKS.

The lifts described in this Paper were designed by the Author and constructed by his firm, Messrs. Easton and Anderson, to meet the specified requirements of Sir James Brunlees and Sir Douglas Fox, the Engineers of the Mersey Railway, under whose supervision the whole of the works were carried out. The machinery was erected by Mr. C. R. May, Assoc. M. Inst. C.E., as Resident for the Contractors.

Each lift is very similar in construction to the large lift at the

Army and Navy Stores in Westminster, but about four times its capacity and power.

The number of lifts at each station, viz. three, was the suggestion of Mr. Francis Fox, after consideration of lift-practice on a smaller scale in the large hotels of the United States. If it had been convenient to put surface stations on each side of James Street and Hamilton Street, two separate lifts might have been carried down to each platform; but probably few passengers will object to walking upstairs to the foot-bridge level, and the station staff is certainly reduced by concentrating the lifts in one building. In some respects it would have been convenient if the three lifts could have been placed symmetrically side by side, but the sites of the stations did not lend themselves well to this arrangement.

Several considerations led to the adoption of low pressure instead of high pressure for working the lifts. A single direct-acting ram was from the first selected by the Author as the safest and best principle to adopt. The average passenger probably weighs less than 10 stones, or 140 lbs. Each lift was proportioned to raise a maximum load of one hundred passengers of about 150 lbs. weight, or 15,000 lbs., when working with the tank-pressure. A large cage was indispensable for so many, and they might crowd to one side, or at one end of it. With 660 lbs. hydraulic pressure per square inch, a 6-inch solid steel ram might be used to give the above lifting power; but a full load on one side of the cage would break such a ram at once transversely, and even as a central load the ram, considered as a column jointed at one end, would be extremely weak at the joints. The 18-inch ram has a margin of safety of about 30 as a column, and about 6·6 under transverse strain, with the full load concentrated at 5 feet from the centre of the cage, towards one side.

The 10,000-gallon supply tank at James Street gives an accumulator storage-power equal to twelve journeys; to give the same reserve power with a ram accumulator for working 6-inch high-pressure lifts would have necessitated a 30-inch ram, 36·7 feet length of stroke, and a load on it of 208 tons. No doubt Sir William Armstrong was right in adopting high pressures and accumulators for scattered duties, but for concentrated lift-service the present arrangement, which is very similar to that first adopted by Sir William Armstrong at the Grimsby Docks, has many advantages.

Great economy of power and freedom in working is obtained by the adoption of leathers instead of packings for the main ram-glands. So far not a single leather has required renewal, and the

Author thinks it probable, from similar experiences, that their average life will be about two years. Packings combined with high pressure are very liable to score the rams, and with careless attendants they entail enormous losses of power in friction, especially in low-pressure lifts.

The water is used over and over again with very slight waste, and getting greasy, much assists the lubrication of the rams, and makes the hand-starting valves work very easily. With fresh water every time, no doubt such large valves would work heavily. The valve faces are purposely made of dissimilar metals, as the Author has found great tendency to "seize" when flat surfaces of the same metal rub heavily on one another in clean water.

The internal cage-floor area is 322 square feet, or 3.22 square feet per passenger. On several occasions crowds of one hundred and forty passengers have travelled up in a cage, and once one hundred and seventy-one are said to have crowded into one, though strict orders are in force limiting the number to one hundred. Sir J. W. Bazalgette and Sir Frederick Bramwell once tested the density of a packed London crowd, and obtained a load of $1\frac{1}{4}$ cwt. per square foot, or one person of 10 stone per square foot. Thus the normal space allowed in these cages per passenger is 3.2 times that for a dense crowd.

Speed.—A convenient speed in these lifts is about 2 feet per second, corresponding to thirty-eight seconds per journey at James Street, and forty-four seconds at Hamilton Street. They are capable of working faster, and as a matter of fact often do so; but the Author does not think high speeds desirable, considering the great inertia of the moving loads, and the responsibilities involved. The total moving mass when a lift is fully loaded is nearly 30 tons. The V-shaped ports and the self-acting flap in the starting-valve make the starting and stopping extremely smooth and pleasant for the passengers.

Guides.—The Author always prefers sliding guides in preference to rollers, which almost invariably wear in flats, and are difficult to adjust and keep from grinding on their flanges.

The accident to a lift at the Grand Hotel in Paris led to many inventions for doing away with balancing chains, but, the Author thinks, without sufficient reason. The accident in question was due to defective construction, such as would never be tolerated in English practice. Hydraulic balancing leads to greater complication of parts, and leaves risks quite as great as those which are avoided. The chains in the present case, combined with the counterweights, serve a very important duty, as they almost

entirely relieve the ram of transverse strain, when a crowd is concentrated at the front or back of the cage, as the weights must be entirely supported by the tighter chains before any appreciable transverse strain can be communicated to the ram. In the Mersey lifts each chain weighs 13·3 lbs. per lineal foot, so that 2 lineal feet of all four chains just about balances the loss of pressure due to the ram rising 1 foot.

Attachments.—The Author assigns the utmost importance to the security of the attachments in lift-construction, especially those of the cage-frame to the ram, the chains to the frame and the counterweight, and the pins in the chain-pulleys. All these are specially guarded, and are easily accessible for inspection.

The platforms round the roofs of the cages give great facilities for the inspection of working parts, oiling and cleaning of guides and pulley-pins, and for adjusting the counterweights without risk to the attendants.

Tests.—The lifts were tested by General Hutchinson, R.E., on the 29th of December, 1885, with a load of about 19,000 lbs. dead weight in each. This load was shifted close to one side of the cage by his direction, and the lift (worked direct by the engines) raised it from the bottom to the top satisfactorily without the slightest appreciable racking of the cage or hard rubbing on the guides.

The total cost of the six lifts, with all their attendant machinery, was about £20,000.

The first cylinder was lowered into place at the end of August, 1885, and the lifts were officially tested and passed for work on the 29th of December, 1885.

The outline calculations for the balancing and variations of loads on the chief working parts are given in an Appendix.

The Paper is accompanied by several drawings, from which Plate 5 and the Figs. in the text have been prepared.

APPENDIX.

CALCULATIONS for BALANCING, and DETERMINATION of VARYING LOADS and STRESSES ON CHIEF WORKING PARTS.

	James Street.	Hamilton Street.
	Levels above datum.	Levels above datum.
High-water level in tower tank	Feet. 390·6	Feet. 414·0
Bottom ditto	382·1	405·5
Average summit level of waste-pipes from lifts discharging into waste- tank	214·1	250·0
Bottom of waste-tank	205·3	241·0
Upper booking-hall floor	271·6	292·2
Lower hall floor	195·0	204·5
Station platform level	182·2	191·7
Engine-room floor	222·2	261·8
Bottom of boring	111·5	109·8
Ram-bottom at top of stroke	190·6	200·0
Ditto, ditto, at bottom of stroke	114·0	112·3
Stroke of lift in feet	76·6	87·7
Effective head of water available for working lifts from top tank	$390·6 - 214·1$ $= 176·5$ feet	$414 - 250$ $= 164$ feet
Corresponding pressure per sq. inch. Area of ram, bare 18 inches diameter Load which could be lifted in perfect frictionless lift infinitely slowly	76·4 lbs. 254 sq. inches 19,405 lbs.	71 lbs. 254 sq. inches. 18,034 lbs.
Practical efficiency allowed for, con- sidering that lift must be able to descend when empty	0·8	0·8
Effective lifting power on up stroke with this efficiency	15,524 lbs.	14,427 lbs.
Average difference between loads on cage and counterweight sides of chain pulleys, to produce motion up- wards when cage is fully loaded, and pressure from top tank is on ram; and also to produce motion down- wards when cage is empty and cylin- der discharging into waste-tank; = half above difference, or 10 per cent. of effective load in perfect machine	$19,405 - 15,524$ $\frac{2}{2}$ $= 1,940$ lbs.	$18,034 - 14,427$ $\frac{2}{2}$ $= 1,803$ lbs.
Weight of water displaced by 1 foot length of ram	110 lbs. = 11 gals.	110 lbs. = 11 gals.
Ditto displaced in full stroke of ram	$76·6 \times 110 =$ 8,430 lbs.	$87·7 \times 110 =$ 9,650 lbs.
Weight of four $1\frac{1}{8}$ -inch chains to- gether, per foot	$4 \times 13·35$ $= 53·4$ lbs.	53·4 lbs.
For perfect balance in all positions, weight of chains per foot should be	$\frac{110}{2} = 55$ lbs.	55 lbs.

	James Street.	Hamilton Street.
Pressure from supply-tank on ram-bottom, at bottom of stroke going up	$\left\{ \begin{array}{l} 390 \cdot 6 - 114 \cdot 0 \\ = 276 \cdot 6 \text{ feet} \\ = 119 \cdot 8 \text{ lbs. sq. in.} \\ = 30,430 \text{ lbs.} \end{array} \right.$	$\left\{ \begin{array}{l} 414 - 112 \cdot 3 \\ = 301 \cdot 7 \text{ feet} \\ = 130 \cdot 6 \text{ lbs. sq. in.} \\ = 33,170 \text{ lbs.} \end{array} \right.$
Ditto at top, going up (= subtracting ram displacement from last)	22,000 lbs.	23,520
Ditto from waste-tank on ram-bottom, when at top of stroke and descending }	$\left\{ \begin{array}{l} 214 \cdot 1 - 190 \cdot 6 \\ = 23 \cdot 5 \text{ feet} \\ = 10 \cdot 2 \text{ lbs. sq. in.} \\ = 2,590 \text{ lbs.} \end{array} \right.$	$\left\{ \begin{array}{l} 250 - 200 \\ = 50 \text{ feet} \\ = 21 \cdot 6 \text{ lbs. sq. in.} \\ = 5,490 \text{ lbs.} \end{array} \right.$
Ditto at bottom, descending (add displacement to last)	11,020 lbs.	15,140 lbs.
<i>Weights affecting Stresses.</i>		
Ram and centre bolt	Lbs. 9,470	Lbs. 10,730
Forged cross under cage floor.	2,400	2,400
2 girders under cage floor, rivets, &c.	3,600	3,600
Iron stirrups.	210	210
4 guide brackets	270	270
Woodwork in cage and seats	13,100	13,100
Lamp, &c.	150	150
Total	29,200	30,460
<i>Weight of Chains.</i>		
Weight on cage side of pulleys at bottom of stroke	$\left\{ \begin{array}{l} 93 \cdot 3 \times 53 \cdot 4 \\ = 4,980 \end{array} \right.$	$\left\{ \begin{array}{l} 104 \cdot 4 \times 53 \cdot 4 \\ = 5,570 \end{array} \right.$
Ditto at top of stroke	890	890
Ditto on counterweight side at bottom of stroke	620	620
Ditto, ditto, at top of stroke	4,710	5,310
<i>To determine Weight of Counterweights.</i>		
Put empty cage at top of stroke and descending very slowly. Then total load on cage side of pulleys—		
= ram, cross, cage, &c. as above	29,200	30,460
Chains on cage side	890	890
Total weight on that side	30,090	31,350
Deduct pressure on ram-bottom from head of water in waste-pipe as above	2,590	5,490
	27,500	25,860
Deduct weight of chains on counterweight side at same time	4,710	5,310
	22,790	20,550
Deduct allowance as above for friction and to produce motion	1,890	1,800
Then total counterweights =	20,900	18,750

	James Street.	Hamilton Street.
	Lbs.	Lbs.
Check at bottom of stroke, cage descending—		
Ram, cage, &c. as above	29,200	30,460
Chains on cage side	4,980	5,570
	<u>34,180</u>	<u>36,030</u>
Deduct pressure on ram from head in waste-pipe	11,020	15,140
	<u>23,160</u>	<u>20,890</u>
Deduct weight of chains on counter-weight side	620	620
	<u>22,540</u>	<u>20,270</u>
Deduct allowance as above for friction and to produce motion. . .	1,890	1,800
	<u>20,650</u>	<u>18,470</u>
N.B.—Differences in above estimates due to deficiency in weight of chains (≈ 3.2 lbs. per foot of stroke) . .	250	280
Taking mean of above figures the counterweights on each side of lift should amount to	<u>10,390</u>	<u>9,300</u>
Variation of pressure upwards at centre of cross due to pressure on ram bottom, less weight of ram, and say $\frac{1}{3}$ of friction allowance—		
Lift at bottom, fully loaded, rising slowly—		
Pressure on ram-bottom, as above . .	30,430	33,170
Less weight of ram and centre bolts, do.	9,470	10,730
	<u>20,960</u>	<u>22,440</u>
Less $\frac{1}{3}$ of friction allowance	630	600
	<u>+20,330</u>	<u>+21,840</u>
Lift at top, fully loaded, rising—		
Pressure on ram	22,000	23,520
Less weight of ram, &c. + $\frac{1}{3}$ friction as above	10,100	11,330
	<u>+11,900</u>	<u>+12,190</u>
Lift empty at top descending slowly—		
Pressure on ram-bottom	2,590	5,490
Less weight of ram	9,470	10,730
	<u>-6,880</u>	<u>-5,240</u>
Add $\frac{1}{3}$ friction allowance	+ 630	+ 600
	<u>- 6,250</u>	<u>- 4,640</u>
	in tension downwards.	
Lift empty at bottom, descending—		
Pressure on ram-bottom	11,020	15,140
Less weight of ram, &c.	9,470	10,730
	<u>+1,550</u>	<u>4,410</u>
Add for friction.	+ 630	+ 600
	<u>+ 2,180</u>	<u>+ 5,010</u>

	James Street.		Hamilton Street.	
	Lbs.	Lbs.	Lbs.	Lbs.
Variation of shearing force at junction of each corner foot of cage-cross with floor-girder.				
Shearing force with lift at bottom, going up slowly loaded—				
Push on cross centre, as above . .	20,330		21,840	
Less weight of cross	2,400		2,400	
	17,930		19,440	
This divided by 4 for number of feet	say	+ 4,480	say	+ 4,860
Shearing force at top, going up loaded, } by similar calculations }	=	+ 2,370		+ 2,450
Shearing force at top, descending empty	=	- 2,170		+ 2,610
Shearing force at bottom ,, ,,		- 110		+ 660
Pull upwards by each chain on end of cage girder.				
Lift at bottom and rising—				
Load on weight side. $\frac{1}{2}$ counterweight	= 5,200		4,650	
Chain	= 160		160	
	5,360		4,810	
Less friction $\frac{1}{4}$ of 630	say 160		150	
	5,200		4,660	
Less long chain on cage side . . .	1,240		1,390	
		3,960		3,270
Ditto with lift at top and rising, } similarly }	=	6,000		5,610
Ditto ditto descending ,,		6,320		5,910
Ditto at bottom ,, ,,		4,280		3,570
Load on each chain-pulley pin with cage at bottom ascending—				
Load on counterweight side of top } pulley }	5,360		4,810	
Ditto ditto cage side	5,200		4,660	
Weight of pulley say	800		800	
		11,360		10,270
Ditto with cage at top and ascending, } similarly }	=	13,400		12,610
Ditto ditto ditto, descending . . .		13,720		12,810
Ditto ditto, bottom ,, . . .		11,680		10,570
Maximum load on each stirrup girder is with cage at top and descending—				
Load on 2 pulley-pins together . .	27,440		25,620	
Weight of 2 stirrups, and girder itself	1,330		1,330	
		28,770		26,950

	James Street.	Hamilton Street.
	Lbs.	Lbs.
Maximum pull on chain on cage side of top pulley, with lift at top and descending	6,540	6,130
Proof test of chains which are of 1½-inch iron	Tons. 15·12	Tons. 15·12
Maximum bending-moment on arm of cage cross at 12 inches from centre of ram	Lbs. Inches. 4,480 × 70 = 313,600 inch-lbs.	Lbs. Inches. 4,860 × 70 = 340,200 inch-lbs.
Section of arm at that point (steel forging)	15 inches deep 2 inches thick }	Ins. Ins. 15 × 2 }
Probable margin of safety at that point, supposed to be its weakest section	14·3	13·2
Maximum bending-moment on ram, supposing full load concentrated at 60 inches to one side of centre of cage	15,000 × 60 = 900,000 inch-lbs.	..
Ultimate moment of resistance of 18-inch mild steel ram ¾-inch minimum thickness at screw threads. (Rankine, f = as per test 63,000 lbs. per square inch)	5,900,000 inch-lbs.	..
Margin of safety	6·6	..
Maximum load on top of ram as a strut at top of stroke (see thrust on cross-centre as above)	11,900 lbs.	12,130 lbs.
Ultimate strength of ram as a strut fixed at one end and jointed at the other, taking it as ¾-inch minimum thickness at screw threads, and only allowing mild steel same strengths as wrought-iron (Rankine)	370,000 lbs.	315,000 lbs.
Margin of safety	31	26

MERSEY RAILWAY LIFTS.

Fig : 1.

Fig : 2.

PLAN AT ENGINE ROOM FLOOR LEVEL.

Fig. : 3.

PLAN AT LOWER HALL FLOOR LEVEL.

Fig : 4.

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Fig : 5.

ARRANGEMENT OF PASSENGER LIFTS

Fig : 6.

SECTIONAL PLANS.

Fig : 7.

VERTICAL SECTION THROUGH CAGE FRAMING RAM & CYLINDERS.