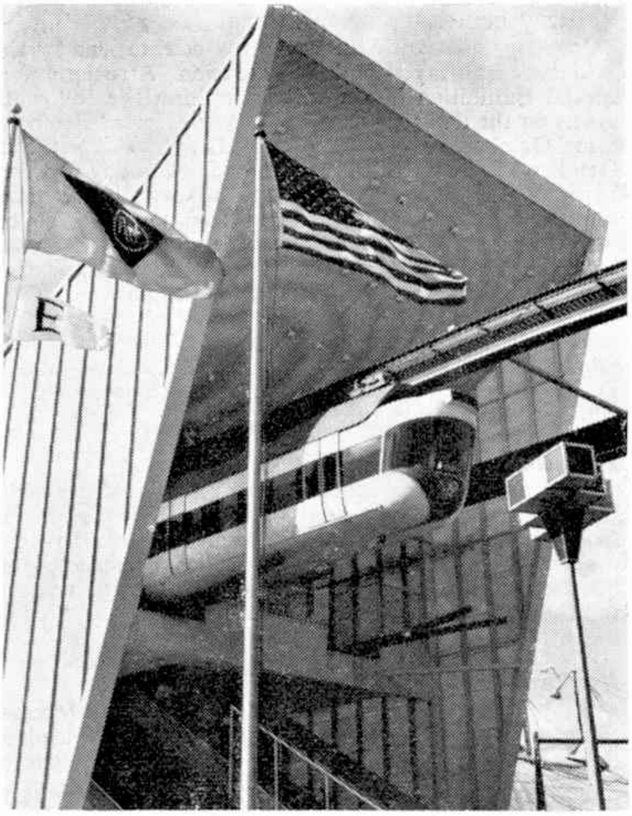


MONORAILS by H. McDougall

The first part of a detailed history of Monorail Railways from the very first monorail of 1821 to the design for future transport

THERE NO longer seems so much doubt of the ultimate success of monorail systems. Several are now operating successfully and many more are contemplated. However, there are still radical differences of opinion on most aspects of monorail design.

The basic problem of whether the monorail car should be suspended from above, or supported from beneath by a beam, is still very much in dispute. However, supported monorails have recently gained much wider acceptance than suspended types.

The very first monorail of which records still exist straddled a wooden beam. It was built by Henry Palmer in 1821 and the beam was supported on wooden posts. The vehicle was fitted with two wheels in tandem, hooks attached to a cross-yolk being used to carry the load. This horse-drawn device proved to be somewhat unstable but it was used successfully for materials handling at a brick yard and in a ship yard.

A monorail supported on wooden "A" frames, built in 1872 to connect Brooklyn with Coney Island, was more ambitious. Several steam locomotives were employed but operations ceased after one year because of inadequate passenger revenue.

Monorail transit systems have achieved a surprisingly high safety record. The only serious accident on record was sustained in 1878 by the Peg-Leg Railroad built to connect Bradford and Gilmore, Pennsylvania.

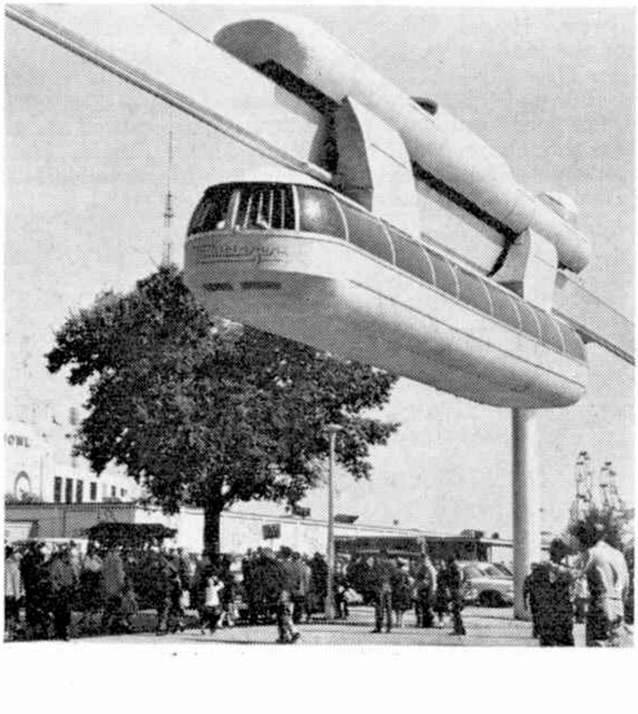
The locomotives, and coaches, were supported on an A-frame structure and stabilised by two auxiliary rails at the cross-bar of the A. The length of the track was six miles and a speed of 30 m.p.h. was achieved.

Three locomotives were built initially and were very successful. A fourth and faster steam locomotive was eventually purchased but it exploded on its first run killing five people. Further operations were suspended.

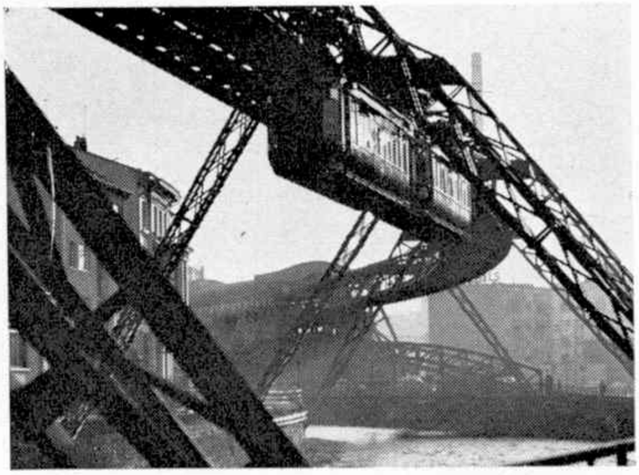
In spite of the ingenuity shown, none of the monorails built in the last century can be considered as more than novelties. It was not until 1901, when the Schwebebahn (literally, "Swinging Railroad") went into service, that the monorail began to come of age. This installation, which connects the German industrial communities of Barfield and Wuppertal, has carried more than a thousand million passengers without a single accident attributable to derailment or structural failure. The track is 9.3 miles long of which 6.2 miles is suspended above the River Wuppertal.

The rail structure above the river is supported by sloped lattice-boxed girders spaced 80 to 110 feet apart, every sixth girder being in the form of a double A frame to compensate for longitudinal stresses. The frames are bridged by horizontal steel plate girders which support the rail 39 feet above the water. For the overland portion, the rails are carried at a height of 26 feet above the ground by a portal type structure.

The original cars, which are still in use, are 37.5



Above, the Safege monorail system as used at the United States World Fair. Here the cars are suspended from bogies. At left, another type of monorail, the U shaped hanger seen in Texas.



The Schwebebahn (Swinging Railroad) system built in Germany during 1901. The original cars are still in use. New lightweight cars are now being introduced to hold 70 passengers.

feet long, 6.75 feet wide, and 8.5 feet high. Each carries fifty passengers and weighs 12 tons. In 1951, twenty new 70-passenger, lightweight cars were introduced.

Each car is suspended from dual two-wheel tandem bogies powered by worm-driven 59 h.p. motors from a 600 volts DC current rail supply. Peak traffic volumes are 4,200 passengers per hour in each direction on an operating headway of two minutes.

The Schwebebahn is often quoted as proof of the high standard of mechanical reliability that a monorail system can attain. However, most proponents of modern monorails systems consider the Schwebebahn as little more than an antique—a curiosity which is no longer representative of modern monorail technology. They feel that its continued existence has tended to retard rather than encourage interest in monorails. One of the reasons for the success of the Schwebebahn is that it occupies air space, above a river, that could not be utilised in any other manner. This circumstance is unlikely to be repeated elsewhere.

Japan is an over-populated country where all new forms of transportation are studied with great interest. An experimental suspended monorail was built in 1957 in the Tokyo Zoological Gardens as the prototype of a proposed mass-transit system. It was designed for a maximum speed of 20 m.p.h., although on the 1,200 feet of rail installed the permitted speed is only 8.5 m.p.h.

The track is a shallow trough on the upper surface of a box girder. The girders and the 23 inverted-J supports were built up from sheet and angle steel.

Each car is 30.5 feet long, seats 31 passengers, and weighs 6 tons. The cars are suspended by U-shaped hangers from two rubber-tired bogies, each powered by a 130 kw motor. Power pickup is by pantograph from a 600 V DC source beneath the beam. The cars are kept in alignment by four small spring-loaded tires mounted on each bogie rolling in a horizontal plane against the outside of the rail.

The cars were fabricated very economically by using components from conventional transit system cars. However, although it is still in operation it was not considered a successful installation. Serious problems were encountered including cracks in the hangers and undue wear on the drive gears.

Another suspended system, developed about the same time as that in Tokyo, was built by Monorail Inc., and installed at the Cotton Bowl, Dallas, Texas. The track is a 30-inch diameter tube with a flat 18-inch wide top. A vertical flange 6 inches high and ½-inch wide is welded down the centre of the top to guide the wheels which contact both sides of the flange. The track is welded to eighteen 30-feet inverted-J steel towers, spaced 55 feet apart and sunk 16 feet into the ground.

The 26,760 lb. air-conditioned coach seats 60 passengers. It is 54 feet long and is powered by two 310 h.p. Packard engines. One engine is installed in the centre of each of the two -four-tired bogies. Eight small guide wheels centre the drive wheels by rolling in a horizontal plane along the sides of the six-inch track flange.

The operator sits in a cockpit above the rail. A speed of 58.5 m.p.h. has been claimed. No sideway and very little sense of motion is felt even at top speed. It has been estimated that if a longer track was installed, speeds of up to 100 m.p.h. would be quite possible.

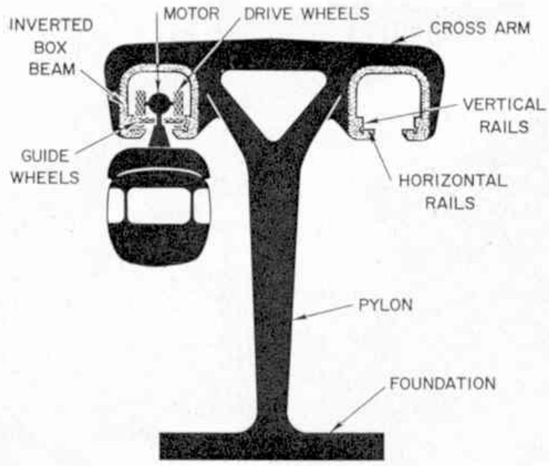
The primary problem faced by monorail designers is that of keeping the per-passenger weight to an absolute minimum. This is vitally important because the lighter the weight of the trains, the fewer the supports needed for the track.

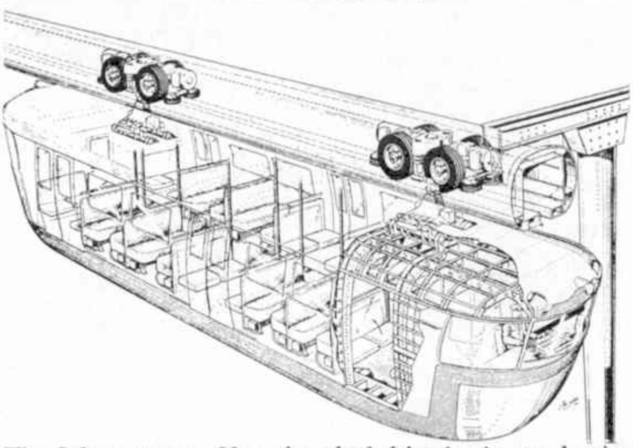
In a conventional transit car a single load-carrying underframe transmits the weight directly to the bogies. The car sides and roof are needed only to enclose the passengers and provide some resistance in the event of a collision.

In a suspended monorail the load must still be concentrated on an underframe but it must then be transmitted to the roof since it is the latter which is connected to the bogies. This means that the entire car must be made very strong. The only alternative is to use massive U-shaped hangers, as in the Texas and Tokyo installations, passing around the car to connect to the underframe. It is thus difficult to design any type of suspended car which is light in weight yet has the required strength factors.

A further complication is that in order to keep the weight imposed at any particular point as low as possible it is desirable that the cars should be long and narrow rather than short and stubby. Unfortunately, this implies that an even stronger roof frame

The Tokyo Hanedh line in Japan showing the " Switch." This type of monorail is just the opposite to the more popular suspended systems, and is rapidly gaining popularity.





The Safege system. Note the wheel drive in the car drawing and the 'T' type supports for double track layouts. The car is suspended 14 feet from the ground, overall height is 30 feet.

is desirable to prevent the car from sagging between the points of suspension. If very high speed monorails are eventually developed the long, slim profile will have the obvious advantage of being more streamlined. But the modest speeds at which present-day monorails operate make streamlining relatively unimportant.

Bogie design presents no particular problems. In most instances use can be made of conventional components long proven in automotive or railroad applications.

The trend in modern monorail systems is toward the use of pneumatic tires rather than steel flanged wheels. Pneumatic-tired stabilising wheels running along the side of the rail tend to increase rolling friction but pose no particular mechanical problems.

Although several types of propulsion have been used successfully in the past, most modern monorails are electrically-powered.

Suspended monorails are much favoured by amusement parks such as the US installations at the Miami Seaquarium and Busch Gardens, Tampa. High Speed operation is not required but it is important to give passengers a good downward view.

The monorail installed at the 1964-65 New York Worlds Fair met these requirements but it was actually a slow-speed version of the most sophisticated suspended monorail yet built—the SAFEGE system erected for experimental purposes at Chateuneuf-sur-Loire near Orleans, France, by a consortium of transportation companies.

Instead of being "hooked" around the rail, the cars used in the SAFEGE system are suspended from bogies which operate inside an inverted box beam fitted with internal rails. The drive wheels run along horizontal rails and the guide wheels bear outward on vertical rails. This system prevents excessive sway and provides a steady ride.

The design of the SAFEGE monorail system was preceded by very extensive investigations of all types, including the supported monorail. The French engineers concluded that the latter presented several problems that could be eliminated in the design of a suspended monorail. These included a tendency toward instability due to the relatively high centre of gravity, and difficulties when short radius curves must be negotiated. Neither of these problems are encountered with suspended systems.

A box girder track, built from plates electrically welded to each other, was found to be the most economical yet efficient structure for maintaining the transverse stability of the cars and trains running at high speeds. Because of the high strength of the box girder, the track requires supports only about every 100 feet. Since the cost of the track installations usually represents more than 50% of the total cost of a monorail system, economy in building the track structure is usually considered to be of major importance.

Other advantages of the box type construction of the rail are that it is completely weather-proof and it reduces even further the already low noise level of the rubber-tired wheels.

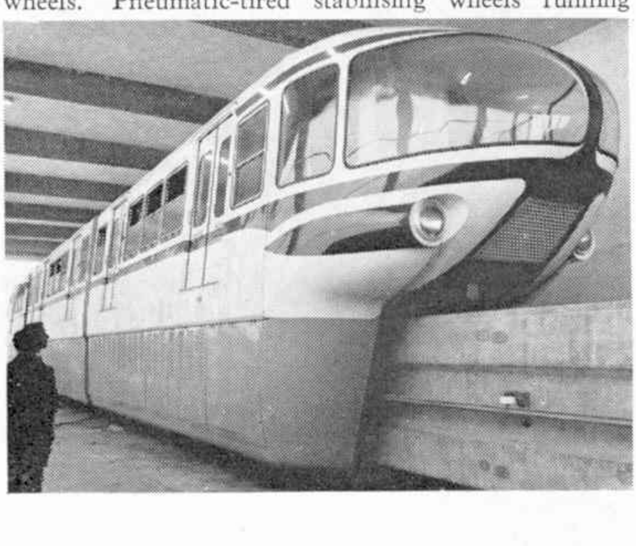
Switching presents no particular problems. The method used for the SAFEGE installations is similar in esentials to that of a conventional railway switch. A central articulated element rotates around an axis at the point of the frog of the switch to establish running and guiding tracks respectively on the straight and turned-out tracks.

The car is constructed of aluminium on the integral shell principle. It weighs 16 metric tons, including the two suspension bogies and is 57 feet long. It can carry 32 seated passengers and 91 standing.

A pneumatic suspension system is employed.

Each of the two overhead bogies has four primary wheels and four small guide wheels. Each bogie has two 600-750 volt traction motors rated for 93/115 h.p. in continuous operation.

A steel safety flange on the wheels eliminates the possibility of accidents caused by tyre blowouts. Rheostat motor braking and air-operated drum or disc brakes operating independently of each other stop the car safely under all circumstances.



This sleek space age monorail is an Italian development and operates on a beam type rail. Note the current pick up rails.

Another view of the Safege monorail system used at the U.S.A. World Fair. This is the most advanced principle in use today.

The light weight of the car, the high traction power and the inherent adhesion of rubber tires, permit fast acceleration and quick stops. Normal operating speeds are 50 to 70 m.p.h.

All experiments made to date with suspended monorails point up the fact that due to the design problems, inherent in the configuration of the cars, they will always tend to be heavy.

Ideally, a monorail would be supported from below but since the centre of gravity of the car would then be above the rail, some means of balancing is obviously required.

During the 1880's, a period sometimes referred to in popular magazines of the time as one of "monorail madness", a device known as the Boynton Bicycle locomotive achieved modest success on Long Island, USA. A steam locomotive which operated over a track two miles long rolled along on a single 8-foot diameter wheel and two smaller tracking wheels. It was stabilised by two dollies extending from the top of the car. They were fitted with wheels that ran in a horizontal plane along each side of an overhead rail.

In 1908 another US experimenter, E. W. C. Kierny, tested a similar system in which the vehicle was stabilised by an overhead guide rail. When it was travelling fast, pressure on the upper rail was reduced almost to zero, but difficulty was experienced at curves. Any variation from the exact design speed caused excessive sideways stresses to be imposed on the guide rail.

In 1909, Louis Brennan in London, sought a more sophisticated solution. He designed a monorail stabilised by a gyroscope. A 40-foot car weighing about ten tons and capable of carrying 40 passengers, ran on a single rail, kept upright by two 1500 pound gyroscopic wheels rotating in opposite directions at 3000 r.p.m. Speeds of up to 125 m.p.h. were theoretically possible, although the question of whether the vehicle could be kept stable as it rounded curves at various speeds was never solved. The project was abandoned primarily because of fear of the gyroscope stopping.

What was required was some system whereby a monorail running along a beam could be made inherently stable, without the need for complex track structures of failure-prone stabilising devices. The solution accepted by present-day designers is to elevate the beam and design a car which straddles it. The power units and all other heavy equipment can then be incorporated into those parts of structure which hang down like panniers on each side of the beam.

This idea was pioneered by the Listowel & Ballybunnion Railroad built in Ireland in 1888. Extending for a distance of 9½ miles it ran on a rail supported by A-frames. Guide rails were installed along each side of the frames. The track was raised about 3½ feet above the ground and the frames were laid on ties positioned parallel to the track. Three engines, 14 passenger cars and 24 freight cars were used.

Each locomotive had twin boilers, fireboxes and cabs. Two cylinders powered the centre wheel of three coupled wheels positioned between the boilers.

This curious contrivance proved quite successful in operation and it continued in service until 1924 when road competition forced its abandonment.

With any beam type monorail, superelevation must be introduced on curves. With careful design this can be calculated so that it will prevent undue sideways motion of the vehicle in normal operation yet permit it to slow down or, if necessary, to stop on curves without disastrous results.

Beam-type monorails now exceed in number all other types. Most of those installed during the last decade stem directly or indirectly from the experiments made by the ALWEG Company, founded by Axel Lennert Wenner-Gren.

The pioneering ALWEG installation was built in 1952 at Fuehlinger Hyde, Germany. for test and exhibition purposes. It operated over a track consisting of a concrete beam which was prefabricated and assembled in sections.

The beam carried five tracks, each made from flat steel, One track on the top of the beam supported the monorail car; two tracks were used at each side to stabilise it.,

All superelevations were cast into the beam. Minimum radius on curves was 444 feet and the maximum banking angle was 45°. The beam was supported by reinforced concrete pylons about eight feet high positioned 20 feet apart.

A three-car train was employed for test purposes, each car being about 30 feet long, 10 feet wide and 12 feet high. Power for the electric motors in each of the dual two-wheeled bogies fitted to each car was collected from a pair of current supply rails on each side of the beamway. The train was controlled automatically from a central off-track cab.

This installation, which was two-fifths full size, proved so successful that it was replaced in 1957 by a full-scale test oval just over a mile long. A two-car unit operates over the installation which includes a station and switch systems.

The beam used is of pre-stressed reinforced concrete, the joints between the sections being covered by finger plates. The conductor rails are recessed in the lateral surfaces of the beam and all electrical cables pass through the inside of the beam.

The dimensions and style of the reinforced concrete pylons designed by ALWEG can be adapted to suit local requirements. The distance between pylons is 65-97 feet but longer distances can be spanned by special structures. Base requirement at street level is only 10-15 feet. Double-tracked sections can be carried on 'T' shaped pylons.

Concluded in next month's MECCANO MAGAZINE

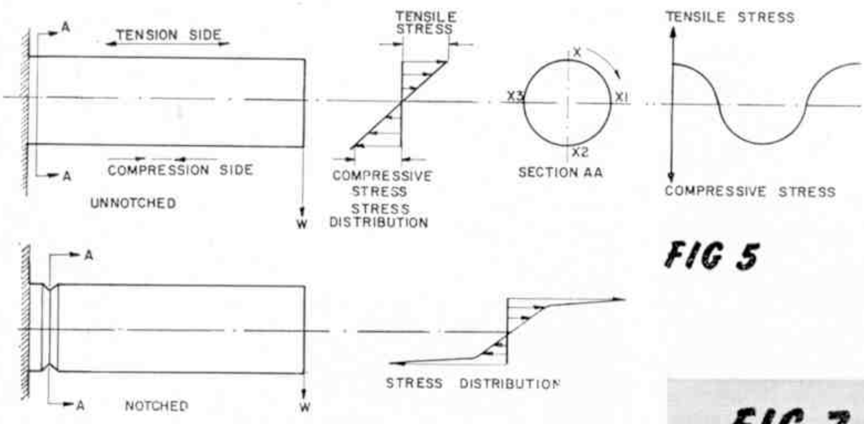
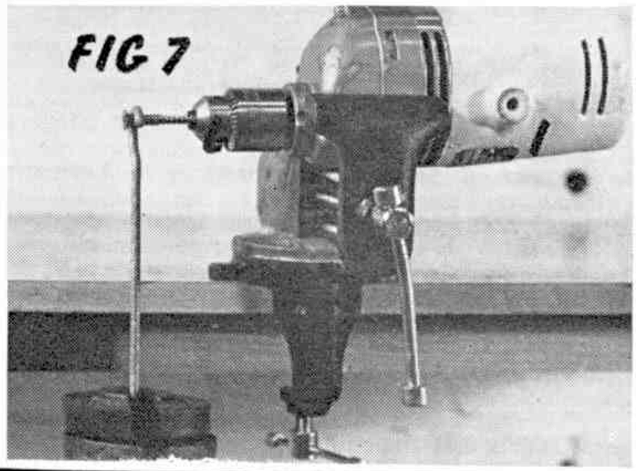
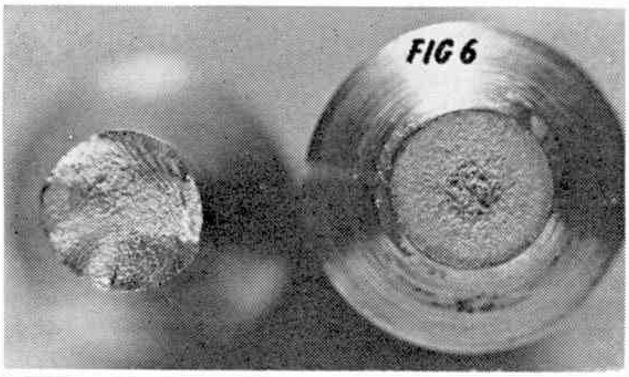


Figure 1: A typical fatigue fracture in a railway rail, the type of thing one reads about in the newspaper. Figure 2: This graph illustrates typical stress levels against the cycles required to fracture. Figure 3: A diagrammatic representation of a rotating vending fatigue machine. Figure 4: The rotating bending fatigue machine with the test specimen just seen as the smallest diameter between the two enlarged bosses. Figure 5: These stress distribution diagrams show that whilst the upper portion of the specimen will be in tension, the lower portion is in compression. Figure 6: Typical fractures due to fatigue under rotation bending. Note one specimen is notched. Figure 7: The use of electric hand drill as a rotating bending fatigue machine.





MONORAILS

by H. McDougall

Last month's Monorail feature concluded

Several versions of the ALWEG monorail are now in operation. One highly successful installation was erected at Turin, Italy. The track is about three-quarters of a mile long and is operated by a three-car unit with a capacity of 340 passengers. It provides a 50 m.p.h. shuttle service between two stations at the north and south ends of the Turin National Exposition grounds.

One notable ALWEG installation in North America is that erected at the Century '21 exhibition in Seattle, in 1962. This double-track line is a mile long and links the exhibition with the centre of Seattle.

Two four-car units running on eight sets of driving and stabilising wheels are capable of carrying 450 passengers operating between the two stations at speeds of up to 60 m.p.h. Each train consists of four cars, is 123 feet long, 10 feet 3 inches wide and 14 feet high and has a total weight of 100,000 lb.

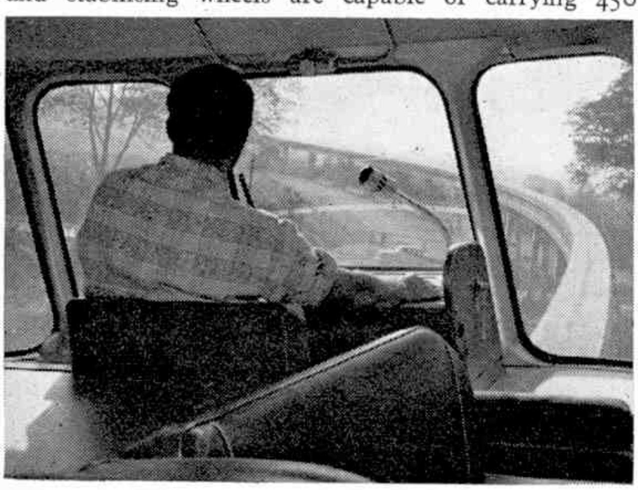
Power is provided by eight 100 h.p. electric motors —one motor for each set of driving wheels—and is transmitted to the wheels from the driving motor by a propeller shaft via a double reduction gear box. Braking is by an air-operated system used in conjunction with dynamic braking; in the case of air pressure failure, the brakes are applied automatically giving a decelleration rate close to the required emergency rate.

Power is 600 volts DC picked up by current collector shoes installed in the monorail cars from contact rails running alongside the beams.

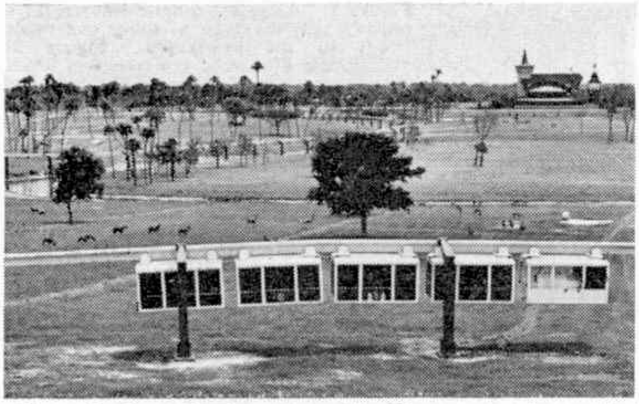
A less ambitious ALWEG installation is that which carries passengers around Disneyland, California. Built in 1959 to a scale of five-eighths that of the original German installation, the track is 2½ miles long.

Three trains are used. Each has four cars, giving a capacity per train of 106 seated people.

A full-scale ALWEG installation utilising two three-car trains with a capacity of 140 persons per train is installed at Yomiuri Recreation Park in the suburbs of Tokyo. The line has an overall length of two kilometers, a maximum gradient of 65 per cent. and a minimum radius of curvature of about 100 meters. This installation is interesting in that it includes two large bridges. It was the second ALWEG system installed



A typical drivers eye view on one of todays many mono-rail railways. Note the spacious cab and radio communication microphone. This one is in Germany.



Above the Busct Gardens monorail. These cars make excellent platforms for viewing the animals. At right another view of the Koln/Fuhlingen Alweg Bahn, in Germany.

in Japan, the first being the Rhine Park Monorail Line of the Nagoya Railroad Co.

Because of the size of the beam or rail, switching of monorail cars will always be more difficult than that of conventional mass-transit vehicles. However, the switches developed for beam-type monorails particularly those on the ALWEG monorail which now connects Haneda airport with the centre of Tokyo have proved very successful in operation. This installation—by far the most ambitious monorail system built to date—may well be the prototype of many similar installations in North America and elsewhere.

Five switches are incorporated into the track. Three are flexible and two are polygon switches. All are of steel construction. Switching time is only ten seconds and the train may be driven safely at a speed of 40 kph.

The Tokyo-Haneda monorail, which has 13.2 kilometers of track, was built by Hitachi Ltd. under licence from ALWEG. The beamways are mostly typical ALWEG prefabricated, prestressed, hollow concrete girders supported on reinforced concrete columns cast in situ. For about 1.5 kilometers of the track—where it runs parallel to and crosses the Tokaido Line of the Japan State Railway—columns and beamways fabricated from steel are employed. These are the only places where the higher cost of the steel structures was considered justified.

Below: These spacious cars are used in the Miama Seaquariam in Miami, Florida, for a terrific aerial view. At right the Tokio suspended system as used in Japan.

The Tokyo-Haneda system has proved that monorails are now thoroughly practical. But research will undoubtedly continue and some engineers feel that monorail cars of the future will ride on air cushions.

The Ford Motor Company advanced this idea some years ago when developing its Levapad system. More recently, the Bertin Company in France has pioneered this type of suspension.

The prime problem an air-cushion monorail raises is that of propulsion. The use of gas turbines driving conventional airplane propellers is one solution, but it might cause unacceptable noise problems. Another possible solution is the use of linear electric motors.

Whatever course future development takes, there is little doubt that a need for mass-transportation systems exists and that it is becoming more acute every year. The problems are now more economic than technical.