

SUPERMETRO - Super-High-Speed-Train in Low Pressure Tunnel

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Abstract

Since the air resistance of high speed railway increases rapidly with speed, especially in tunnel, the railway in vacuum even with use of gravity is proposed in USA in about 1956 and the development of it was initiated in Switzerland in about 1980 as "Swissmetro". The application of it to Japan was investigated in this study group set in that as of Himalaya, but not in 0.1 atm which has been considered to be necessary for the system so far. It suggests that this system could be realized with technologies in hands.

1 Introduction

350km/h operation of conventional steel wheel on steel rail system is planned for Madrid-French border line in Spain and TGV east line in France, also 360 km/h operation is planned for Tohoku Shinkansen in Japan. In addition, 430km/h operation of magnetic levitation system, called maglev for short, is realized in Shanghai's, China and 500km/h operation of maglev is aimed at in Japan.

In such a high speed operation, air resistance of train running and air temperature in tunnels increase responding to the increase of running speed. To cope with this situation or moderate such a severe condition, cross-section area ratio of train to tunnel which is defined as the ratio of the vehicle cross section divided by the effective area of tunnel inside cross section without obstacles for train running, hereinafter called R, should be small, which means the larger cross section of tunnels must be constructed against the vehicle cross section. This should be economically and physically poses a big problem. Low vacuum tunnel in which air pressure is decreased was considered and the concept of vacuum and gravity railway, whose tunnel was constructed with slope for making use of gravity, was proposed in USA in 1965[1]-[3].

This idea was adopted in Switzerland in 1980s afterwards and Swiss metro company was established to make a plan of the details of the system and invested 17.345 million CHF mainly to technical University of Lausanne to develop the system. If the project succeeds, additional 4 million CHF will be planned to invest in coming two years. The plan of Swiss metro is as follows[4]:

- Single track tunnel whose diameter is 5m and is constructed under 50m from the surface
- Atmospheric pressure is decreased to 0.1 atm.
- Vehicle whose capacity of passengers is 400 and, levitated and driven with liner motor propulsion.
- The system makes it possible to link main cities in Switzerland each other within one hour.
- Lyon-Vienna is linked for 2 hours and 15 minutes as Euro metro extended from Swiss metro in the future.
- Experiments will be carried out in a test line up 15 years later and commercial operation of a pilot line is planned to begin up to 20 years later.

A study group, which was named as new systems of high speed railway including decompressed tunnel railway, was established in railway structure sub-committee in structural engineering committee in the Japan Society of Civil Engineers to apply the Swiss metro system to Japan in 2004. The group investigated the possibility to adopt the modified system to the distance of 80km corresponding to Tokyo-Narita international airport[5],[6].

2 Critical cross-section area ratio of train to tunnel

The cross-section area ratio of train to tunnel R is decided considering above mentioned various parameters. R 0.12 of Yamanashi maglev test line and R 0.25 in San-yo Shinkansen are shown in Figs.1[7] and 2[8]. At first, the upper limit of R has been investigated with the focus placed on the possibility of enlarging R because of depressurization.

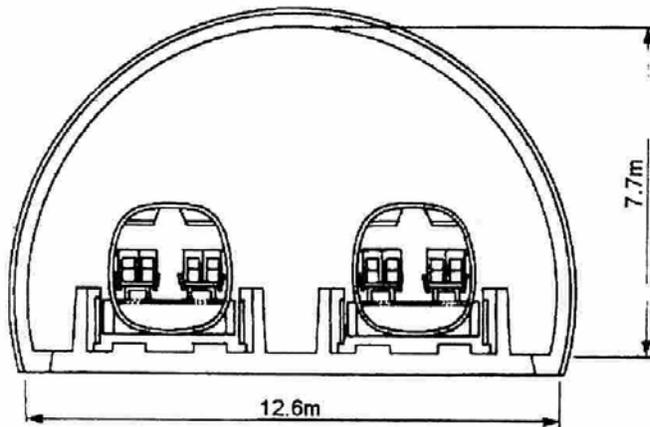


Fig. 1 Yamanashi Maglev test line ($R=0.12$)

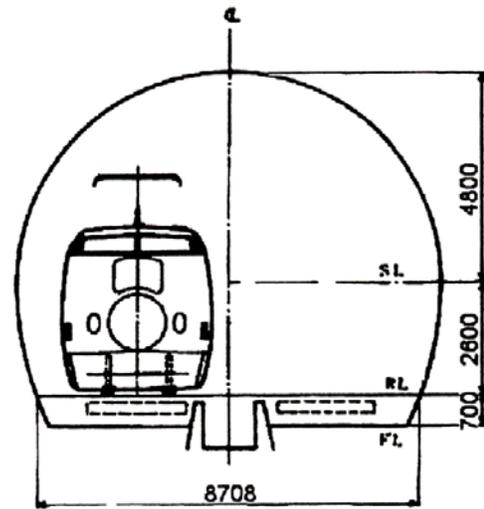


Fig. 2 San-yo Shinkansen ($R=0.22$)

The limit for railway vehicle moving dimensions is assumed to be 3m (width) \times 3.5m (height) which is the same size as the one in Yamanashi maglev test line. The limit for construction to secure the safety of train running is not taken into account to extend like Yamanashi maglev test line for aero-dynamic system installed in vehicles because air resistance of vehicle is decreased by decompression. Double-track tunnel being focused on, the lateral space between the two vehicles placed on in parallel in tunnels and 0.5m of guideway width for vehicles, and the limit of the radius of circular tunnel should be 4.2m considering the lateral size of the tunnel as shown in Fig.3. The tunnel cross section should be 35.1m² and the vehicle cross section should be 8.9m² were estimated by reducing invert and guideway cross sections from the circular tunnel cross section, the following which the feasible critical R_c is estimated to be 0.25. Also, in the case of single track parallel two tunnels, the feasible critical R_c is estimated to be 0.59 as shown in Fig.4.

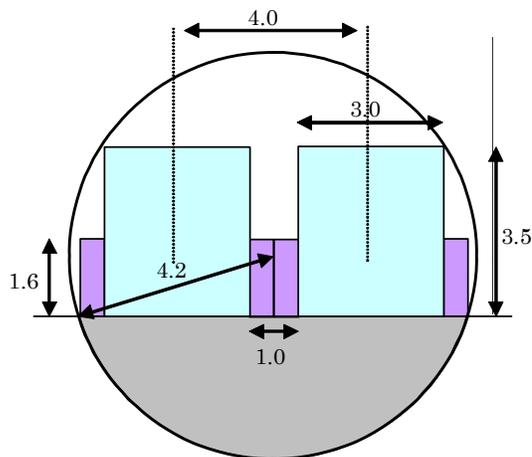


Fig. 3 Double-track tunnel ($R_c=0.25$)

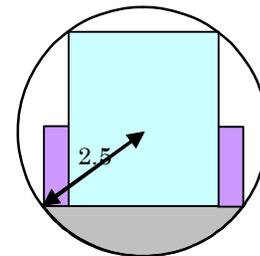


Fig. 4 Single track tunnel ($R_c=0.59$)

3 Numerical analysis for air resistance of train under decompression[5]

In this analysis, air flow in the tunnel is treated as unsteady one-dimensional flow and pressure wave caused in the tunnel is taken into account but compressibility of air is not considered. Fig.5 shows the three cases analyzed here. The both open edges of double-track tunnel under normal air pressure, the both closed edges of double-track tunnel under decompression and the both closed edges of single track parallel two tunnels with four pressure relief ducts between the parallel two tunnels were analyzed. Table 1 gives main parameters for analysis. The analyzed results are as follows:

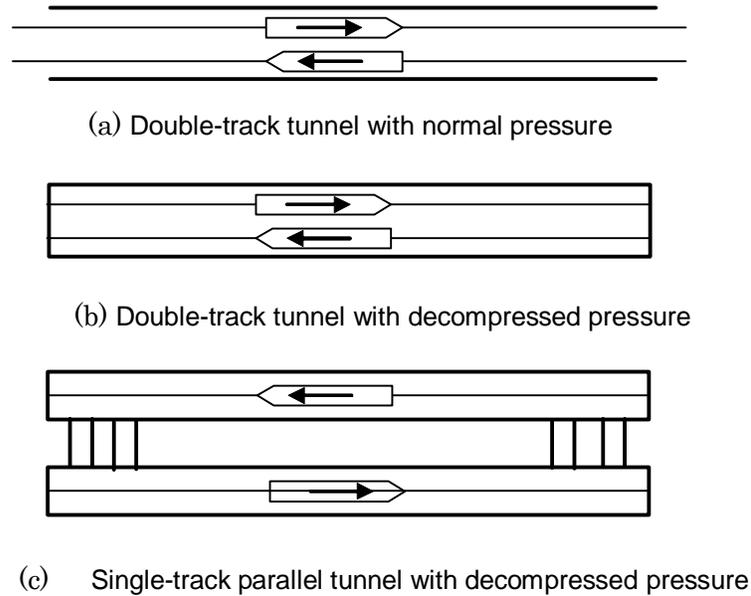


Fig. 5 Schematic structures for analysis

	Train	Tunnel	Pressure relief duct
Cross section (m ²)	8.9	*	12.56
Hydraulic diameter (m)	3.04	*	4.0
Length (m)	350	57000	30
Hydraulic skin COF ⁺	0.013	0.020	0.020
Form drag coefficient	0.2		

* Decided by sectional ratio R, + Coefficient of Friction

Table 1 Details of main parameters

(1) Normal double-track tunnel

Air resistance of normal double-track tunnel is shown in Fig.6. The averaged values are plotted in the figure because the air resistance is unsteady due to the influence of pressure wave. In this figure, white square and triangle indicate the relative air flow velocity between vehicle and air flow or against trains locally reaches to almost the velocity of sound, which means the application limit for the numerical model. Also, air resistance is proportional to the second power of train running speed under the same cross-section area ratio of train to tunnel R.

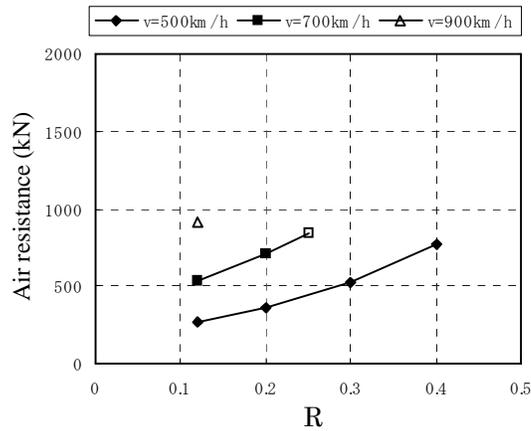


Fig. 6 Air resistance in normal pressure tunnel

(2) Decompressed double-track tunnel and single track parallel two tunnels

Air resistance of double-track tunnel and single track parallel two tunnels decompressed to 0.1 is shown in Fig.7. Comparing Fig.6 with Fig.7, air resistance comes to be 1/10 in proportion to atmospheric pressure. In case the total across section of single track parallel two tunnels is equal to the across section of double-track tunnel and the speed of train is 700km/h, the air resistance of train in the double-track tunnel of R0.2 comes 73kN and that in the single track parallel two tunnels of R0.4 comes 128kN, which means the air resistance of double-track tunnel is 60% of that of single track parallel two tunnels.

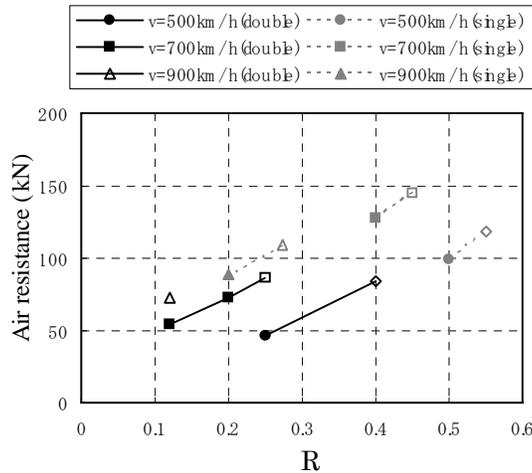


Fig. 7 Air resistance in decompressed pressure tunnel (0.1atm)

(3) Discussions

Feasible R was estimated under some limits of relative air flow velocity against trains and air resistance of train running in tunnels. Limit of relative air flow velocity was the velocity of sound (340m/s at 10) and that of air resistance caused by train running was 267kN which was the same as that of R0.12 in Yamanashi maglev test line. Some analyzed results close to the limit of parameter were shown in Tables 2 and 3 with bold face.

Atmospheric pressure (atm)	Train speed (km/h)	Sectional ratio R	Air resistance (kN)	Maximum relative air flow velocity Against trains (m/s)
0.1	500	0.40	83.7	320.
	700	0.25	86.5	339.
	900	0.12	72.1	345.
0.5	500	0.25	231.	207.
	700	0.12	271.	241.

Table 2 Limits of parameters calculated in the case of double-track tunnel

Atmospheric pressure (atm)	Train speed (km/h)	Sectional ratio R	Air resistance (kN)	Maximum relative air flow velocity against trains (m/s)
0.1	500	0.55	119.	321.
	700	0.45	145.	345.
	900	0.27	109.	342.
0.5	500	0.3	239.	202.
	700	0.12	254.	218.

Table 3 Limits of parameters calculated in the case of single-track tunnel

The relative air flow velocity was critical in the case of 0.1atm and the air resistance of train running was critical in the case of 0.5atm. In the case of 900km/h of train running speed, R0.12 of double-track tunnel and R0.27 of single track parallel two tunnels were estimated under 0.1atm as the smallest R of the tunnels. Also, in the case of 700km/h, R0.25 of double-track tunnel and R0.45 of single track parallel two tunnels were needed under 0.1atm and R0.12 of both double-track tunnel and single track parallel two tunnels were needed under 0.5atm. Then, in the case of 500km/h, R0.4 of double-track tunnel and R0.55 of single track parallel two tunnels under 0.1atm, and R0.25 of double-track tunnel and R0.3 of single track parallel two tunnels under 0.5atm were estimated.

4 Feasible plan

Fig.8 shows the image of investigated feasible plan. Comparing the current plan of R0.12 under normal air pressure of 1.0atm in Yamanashi maglev test line, initial running speed of 500km/h in R0.25 of double-track tunnel or in R0.3 of single track parallel two tunnels under 0.5atm can be increased 700km/h under 0.1atm. In the case of further speed up in the double-track tunnel, if the double-track tunnel of R0.12 is constructed, trains can run at the speed of 700km/h under 0.5atm and 900km/h under 0.1atm. The cross-section area ratio of train to tunnel R is actually selected from R0.12 of the case of Yamanashi maglev test line to critical Rc based on the future running speed of train in consideration of total cost including construction cost, decompression cost, energy cost, maintenance cost, environmental cost, vehicle construction cost and social benefit

With regard to tunnel construction cost, the cost decreases in proportion to the cross section of tunnel in terms of the cost estimation based on simplifying tunnel models. Also, in comparison with the cost of double-track tunnel and that of single track parallel two tunnels under the same condition of air pressure level, the parallel two tunnels can be a bit more expensive than that of double-track tunnel. That is why single track parallel two tunnels must be equipped with pressure relief duct between the two tunnels. Somehow, both double-track tunnel and single track parallel two tunnels can be constructed by 60% of the construction cost of the tunnels under normal atmospheric pressure of 1.0atm. On the other hand, the cost of pumping for decompressing and keeping the same pressure inside the tunnels is far much smaller than that of tunnel construction, however, some factors for increasing cost, for example, related to lock structure for connecting normal pressure section with low pressure section must be investigated. The step by step promoting image of the project shown in Fig.7 makes it possible to improve the safety in the case of vehicles caused some damages comparing with the case of 0.1atm supposed previously. In addition, if

the air pressure inside vehicles is reduced like aircraft, the difference between air pressure inside the vehicle and outside the one becomes small. Then the safety of the system will be more improved.

Some foreign countries are proposing and promoting the system of 500km/h operation in single track parallel two tunnels under 0.1atm. Japan has already developed the maglev system of 581km/h record and a lot of experience of constructing double-track tunnel so that the system of 500km/h operation in double-track tunnel under 0.5atm can be established. Then the cost of tunnel construction can be reduced very much comparing with the normal pressure tunnel. Also, decreasing air pressure inside the tunnel more, speed up can be achieved and some other advantages can be obtained from the technological point of view. Further more, if the construction of very deep tunnels is combined with this project, the ecologically friendly system by which noise and ground vibration can be almost sorted out can be established. We are proposing this concept as SUPERMETRO.

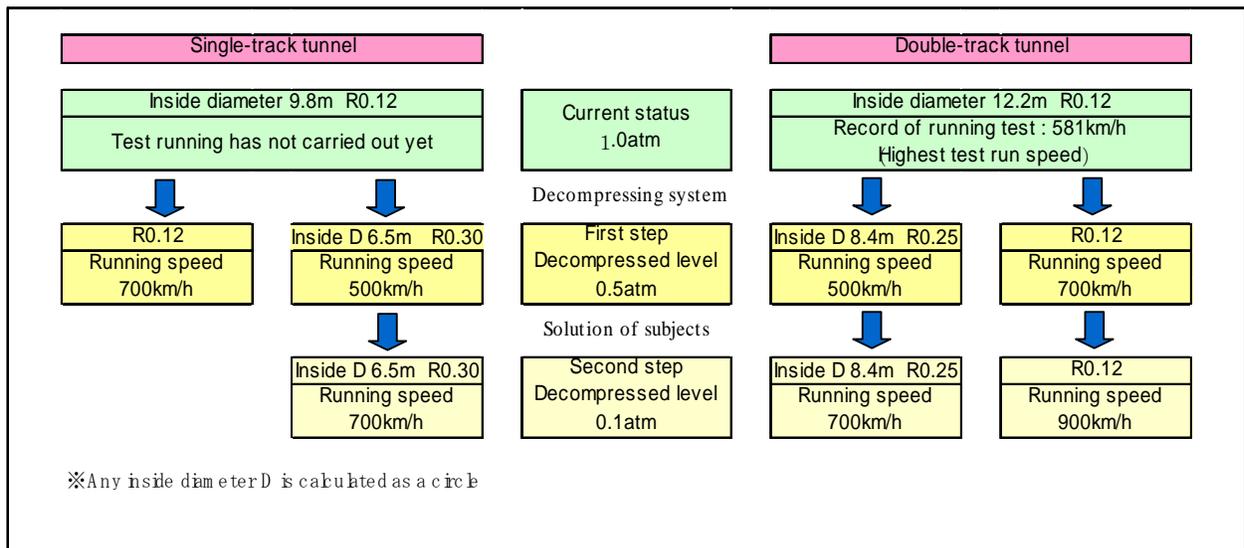


Fig. 8 Image of progressing step by step

5 Further study

Realizing this project a lot of subjects can be identified into the following classification; The details of tunnel design, Decompression facility, Vehicle, Station, Aero-dynamics, Safety, Geometrical condition, Promoting organization of the project. In particular, the influence of the system on human body, the structure of station and vehicle, the airtight characteristics of tunnel and aero-dynamics characteristics considering compressive flow. With regard to the operational cost of the system, the propulsion system will be based on Yamanashi maglev test line, but the further study will be expected from the aspect of life cycle costing related to the selection of the cross-section area ratio of train to tunnel R.

Acknowledgements

This concept was established after investigation and study carried out by study group of reference [5]. The authors were selected from the members of the group considering the responsibility of this paper.

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