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Maglev

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1. Introduction

Magnetic levitation (maglev) is a highly advanced technology. It is used in the various cases, including clean energy (small and huge wind turbines: at home, office, industry, etc.), building facilities (fan), transportation systems (magnetically levitated train, Personal Rapid Transit (PRT), etc.), weapon (gun, rocketry), nuclear engineering (the centrifuge of nuclear reactor), civil engineering (elevator), advertising (levitating everything considered inside or above various frames can be selected), toys (train, levitating spacemen over the space ship, etc.), stationery (pen) and so on. The common point in all these applications is the lack of contact and thus no wear and friction. This increases efficiency, reduce maintenance costs and increase the useful life of the system. The magnetic levitation technology can be used as a highly advanced and efficient technology in the various industrial. There are already many countries that are attracted to maglev systems.

Among above-mentioned useful usages, the most important usage of magnetic levitation is in operation of magnetically levitated trains. Magnetically levitated trains are undoubtedly the most advanced vehicles currently available to railway industries. Maglev is the first fundamental innovation in the field of railroad technology since the invention of the railroad. Magnetically levitated train is a highly modern vehicle. Maglev vehicles use non-contact magnetic levitation, guidance and propulsion systems and have no wheels, axles and transmission. Contrary to traditional railroad vehicles, there is no direct physical contact between maglev vehicle and its guideway. These vehicles move along magnetic fields that are established between the vehicle and its guideway. Conditions of no mechanical contact and no friction provided by such technology makes it feasible to reach higher speeds of travel attributed to such trains. Manned maglev vehicles have recorded speed of travel equal to 581km/hr. The replacement of mechanical components by wear-free electronics overcomes the technical restrictions of wheel-on-rail technology. Application of magnetically levitated trains has attracted numerous transportation industries throughout the world. Magnetically levitated trains are the most recent advancement in railway engineering specifically in transportation industries. Maglev trains can be conveniently considered as a solution for transportation needs of the current time as well as future needs of the world. There is variety of designs for maglev systems and engineers keep revealing new ideas about such systems. Many systems have been proposed in different parts of the worlds, and a number of corridors have been selected and researched (Yaghoubi, 2008).

Rapid growth of populations and the never ending demand to increase the speed of travel has always been a dilemma for city planners. The future is already here. Rapid transit and high-speed trains have always been thought of and are already in use. This is the way further into the future. Trains with magnetic levitations are part of the game. Conventional railway systems have been modified to make them travel at much higher speeds. Also, variety of technologies including magnetic levitation systems and high-speed railway (HSR) systems has been introduced. Rapid development of transportation industries worldwide, including railroads and the never ending demand to shorten travel time during trade, leisure, etc. have caused planning and implementation of high-speed railroads in many countries. Variety of such systems including maglev has been introduced to the industry. Maglev trains are a necessity for modern time transportation needs and vital for the future needs of railways, worldwide. This has resulted in the development of a variety of maglev systems that are manufactured by different countries. Maglev systems currently in use have comparable differences. The current models are also changing and improving.

Industries have to grow in order to facilitate many aspects of modern day life. This comes with a price to pay for by all members of socities. Industrial developments and widespread use of machineries have also increased risks of finanicial damages and loss of lives. Safety and needs to physically protect people against machineries may have not been a priority in the past but they are neccessities of modern times. Experts of industries have the task of solving safety and protection issues before implementing machineris. This is a step with high priority for all industrial assignments. While being fast, relaible and comfortable, maglev systems have found special places in minds of people. Running at such high speeds, maglev sytems have to be safe and need to be renown for safety. This puts much heavier loads on the shoulders of the corresponding experts and managers, compared to some other means of transportation. Safety is knowingly acting with proper functions to provide comfort and reduce dangers, as much as possdible. Risk management techniques have a vital role in organizing and implementing proper acts during incidents, accidents or mishaps in maglev systems operations. Effective management has a specific place in such processes. Obviously, such plannings put considereable finanicial load on the system. Implementation of internationally accepted standards is a fundamental step toward uplifting track safety. It will also serve to improve route quality, increase passenger loads and increase speed of travel. Maglev vehicle is one of the important transportation equipment of the urban track traffic system toward the future (Wang et al., 2007).

The overall plan for research and development and application of maglev technology should be made at the national level. This plan shall include the development plans as to research and development of key maglev technology, project implementing technology research and development of maglev project, plans of building maglev passage based on traffic demands, investment and financing system for the construction and operation of maglev system, research on implementing plans of high-density operational organization and maintenance of maglev route and so on.

It is very important to be vigilant about economical aspects of any major project during its planning and construction phases. Optimal use of local resources must be all accounted for. Technical and economical evaluation of the projects is a necessity to their success. It is necessary to have prior knowledge for investing into a project and then implementing its goals. Good planning makes it feasible to run the projects with reduced risks and increased return for the investment.

2. Vehicle

Maglev suspension systems are divided into two groups of ElectroMagnetic Suspension (EMS) and ElectroDynamic Suspension (EDS). There are varieties of vehicles that are manufactured based on these two types of systems. Vehicle path in EMS and EDS systems are called guideway and track, respectively. Basically, there are two main elements in a maglev system including its vehicle and the guideway. The three primary functions in maglev technology are levitation, propulsion, and guidance. Magnetic forces perform all of these. Magnets are used to generate such magnetic forces. For EMS systems, these magnets are located within the vehicle while for EDS systems magnets are located in the track. Performance of EMS system is based on attractive magnetic forces, while EDS system works with repulsive magnetic forces. In EDS system, the vehicle is levitated about 1 to 10 cm above the track using repulsive forces as presented in Fig. 1. In EMS system, the vehicle is levitated about 1 to 2 cm above the guideway using attractive forces as presented in Fig. 2. In EMS system, the electromagnets on the vehicle interact with and are attracted to levitation rails on the guideway. Electromagnets attached to the vehicle are directed up toward the guideway, which levitates the vehicle above the guideway and keeps the vehicle levitated. Control of allowed air gaps between the guideway and vehicle is achieved by using highly advanced control systems. Figs. 1, 2 show the components of the guideway and track including levitation and guidance systems in aforementioned maglev systems.

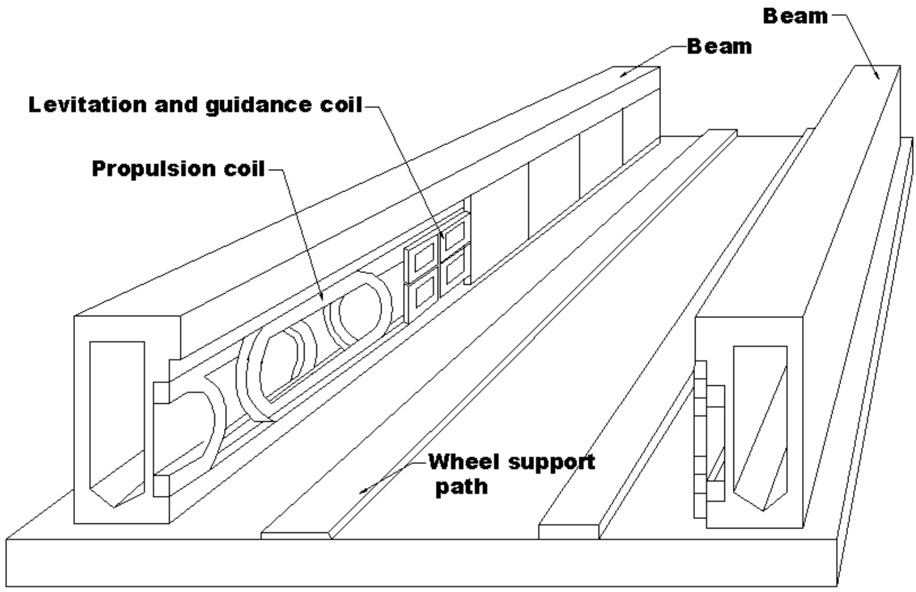

Fig. 1. Schematic diagram of EDS maglev system

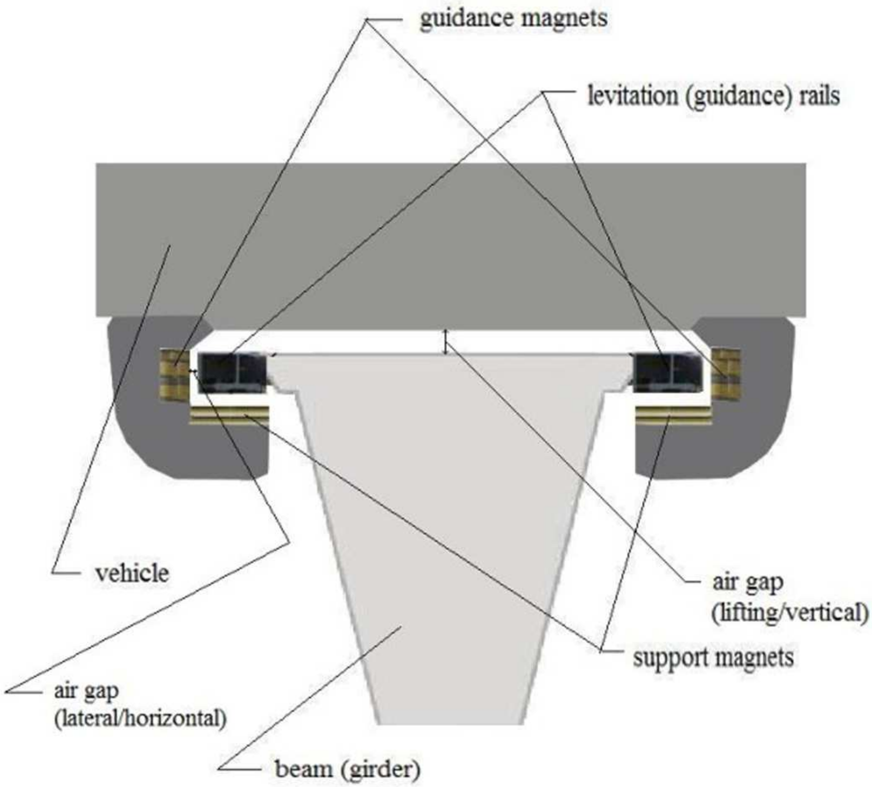

Fig. 2. Schematic diagram of EMS maglev system

Germany and Japan are clearly the front runners of the maglev technology. German's Transrapid International (TRI), a joint venture by Siemens AG and ThyssenKrupp, with EMS system has presented ninth generation of its maglev vehicles namely TR01 to TR09. TRI has been investigating electromagnetic levitation since 1969 and commissioned TR02 in 1971. The eighth generation vehicle, TR08 operates on 31.5 km of the guideway at Emsland test track in northwest Germany. The contract for implementing the world's first Transrapid commercial line was signed in Shanghai in January 2001. Construction work of the Shanghai Transrapid line began in March 2001. After only 22 months of construction time, the world's first commercially operated Transrapid train made its successful maiden trip on December, 31 2002. On December, 2003, the world's first commercial Transrapid line with a five section train started scheduled operation in Shanghai. TR08 and TR09 vehcles are used for the Shanghai Maglev Train (SMT) and TR09 Munich project, respectively. TR08 consists of 2 to 10 car bodies. SMT consists of 5 car bodies and travels on a 30km double-track elevated guideway, connecting the LongYang Road station (LYR), served by Metro Line 2 situated in the Pudong trade centre in Shanghai, to the Pudong International Airport (PIA). High-speed signifies operation of at least at $250_{km/hr}$. SMT has reached to the record speed of $501_{km/hr}$, a average speed (peak operating speed) of $431_{km/hr}$ and average speed of $268_{km/hr}$.

In 2005, China built its own maglev train. This train reached to the test speed of 150$_{km/hr}$ over a track length of 204m. In February 2006, Chinese government announced that they decided to extend Shanghai maglev to Hangzhou city the capital of Zhejiang province. It would create the world's first intercity maglev line. The project will be managed by a German consortium leaded by Siemens Company. This route is of 170 to 175 km in length. The Ministry of Railways chief planner said in March 2010 that China had agreed to build a maglev line between Shanghai and Hangzhou. The line will start construction this year, Xinhua news agency reported. The new link will be 199.5 kilometers, about 24 kilometers longer than that included in the 2006 plan. The top speed of the maglev will be 450 kilometers per hour. It will take about half an hour to travel from Shanghai to Hangzhou, a trip which usually takes one and an half hours on the current service. The new line will also contain a downtown section of about 34 kilometers which is expected to connect the city's two international airports, Pudong and Hongqiao.

Maglev transport system features its potential development in a region with fast growing demand of intercity travel, such as the Shanghai maglev transport system (Yau, 2009). Growth of maglev technologies originated from human's pursuit of travel speed. Since the past 80 years, a number of scientists have made several researches on the feasibility of applying this transport technology. Eventually, they have realized commercial operation in Shanghai, China. Since China has a large population, the demand of applying this technology not only comes into being in the intercity long-distance transport but also in the city traffic field, which is mainly materialized in the low-speed technology and light vehicles (Siu, 2007). The Shanghai maglev line solved many important problems concerning the practical use of maglev transportation system. It has proved that the maglev technology is mature and can be put into practical application with good safety and reliability (Luguang, 2005). The construction data and operational experience of Shanghai maglev route create quite advantaged conditions for the application of maglev technology in China. It is also a blessed advantaged condition for research and development of maglev technology of China. Therefore, to share and make full use of the experiences and technical data of this operational route at national level may promote the research and development progress of maglev technology in China (Baohua et al., 2008).

In field of low-speed maglev systems, the National Defense University and the South South-West Jiaotong University worked for a long time for the development of the system similar to Japanese HSST. The Beijing Enterprises Holdings Maglev Technology Development Co. together with the National Defense University built a CMS-03 test vehicle and a 204m long test line with minimum radius of 100m and maximum climbing of 4% in 2001 in Changsha. Up to now, the vehicle traveled over 7000 km with over 20,000-test run and 40,000 times start and stop operations, its safety and reliability are proved. Recently, based on the test results a new engineering prototype vehicle has been constructed. It is planned to build a 2 km test and operation line in Kunming, after all necessary testing is finished. The whole system can be accepted for real urban application in 3-5 years (Luguang, 2005).

Technical specifications of high-speed and low-speed maglev trains are presented in Table 1 and 2, respectively (Yaghoubi & Sadat Hoseini, 2010).

<table>
<tr><th>Country</th><th>System</th><th>Suspension</th><th>Performance</th><th>Levitation</th><th colspan="2">Vehicle</th><th>Car-body</th><th>Speed</th><th>Year</th></tr>
<tr><td rowspan="5">German</td><td rowspan="5">TRI</td><td rowspan="5">EMS</td><td rowspan="5">Attractive force</td><td rowspan="5">At low speed and even at standstill</td><td colspan="2">TR06</td><td>2</td><td>392</td><td>1987</td></tr>
<tr><td colspan="2">TR07</td><td>2</td><td>450</td><td>1993</td></tr>
<tr><td rowspan="2">TR08</td><td>TR08</td><td>3</td><td>500</td><td>1999 (German)</td></tr>
<tr><td>SMT</td><td>5</td><td>501</td><td>2003 (Shanghai)</td></tr>
<tr><td colspan="2">TR09</td><td>3</td><td>350</td><td>2008</td></tr>
<tr><td rowspan="7">Japan</td><td rowspan="7">Railway Technical Research Institute (RTRI) and JR (Japan Railways) Central</td><td rowspan="7">EDS</td><td rowspan="7">Repulsive force</td><td rowspan="7">At speeds higher than 100km/hr</td><td colspan="2">ML-500R</td><td>1</td><td>517</td><td>1979</td></tr>
<tr><td colspan="2">MLU001</td><td>2</td><td>405</td><td>1980-1982</td></tr>
<tr><td colspan="2">MLU001</td><td>3</td><td>352</td><td>1980-1982</td></tr>
<tr><td colspan="2">MLU002</td><td>1</td><td>394</td><td>1987</td></tr>
<tr><td colspan="2">MLX01</td><td>3</td><td>550</td><td>1997</td></tr>
<tr><td colspan="2">MLX01</td><td>5</td><td>552</td><td>1999</td></tr>
<tr><td colspan="2">MLX01</td><td>3</td><td>581</td><td>2003</td></tr>
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Table 1. Characteristics of high-speed maglev trains

Country	U.S	U.S	U.S	U.S	U.S	Korea	Indonesia	Japan
System/ Project	Magne Motion	GA (General Atomics)	CDOT[a]	AMT[b] / ODU[c]	M2000	MOCIE[d]	Jakarta	HSST[e]
Vehicle	M3	-	HSST-200 Colorado 200	-	-	-	-	HSST-100L
Suspension	EMS	EDS	EMS	EMS	EDS	EMS	EMS	EMS
Max. Operation Speed (km/hr)	160	80	200	64	-	110	110	100
Max. Initial Acceleration (m/s^2)	2	1.6	1.6	-	2	-	1	1.1
Capacity (pphpd[f])	12000	12000	6000	-	-	-	-	-
Passenger Capacity (One Car)	-	100	Seated: 103	Standin: 100	Seated: 50-100	100	Seated: 33 Standing: 67 Total:100	100
Air gap (mm)	20	25	-	10	100	-	10	-
Service Brake Max. Deceleration (m/s^2)	1.6	1.6 (standing) 2.5 (seated)	1.25	-	2	-	1	1.1
Emergency Brake Max. Deceleration (m/s^2)	-	3.6	3.1	-	4	-	1.25	1.1
Car-body	-	1	2	1	-	2	-	2
Number of Bogies in each Car body	-	2	5	2	-	-	-	5
Number of Magnets in each Bogie	-	-	4	6	-	-	-	-
length of each car body (m)	-	13	24.3	13.5	20- 30	13.5	13.5	15
Car width (m)	-	2.6	3.2	-	3.3	28.5	28.5	-
Car height (m)	-	3	3.65	-	3	3.5	3.53	-
Vehicle weight (ton)	-	Empty: 12 75% Loaded: 17.6	44	Empty: 11.5	Empty: 19.5-27 75% Loaded: 23.5- 36	28.5	Empty: 21 75% Loaded: 27.5	-

(a) Colorado Department of Transportation
(b) American Maglev Technology
(c) Old Dominion University
(d) Ministry of Commerce, Industry and Energy
(e) High Speed Surface Transport
(f) pphpd: passengers/hr/direction

Table 2. Characteristics of low-speed maglev trains

3. Guideway

The guideway is the structure that maglev vehicles move over it and are supported and guided by it. Its main roles are: to direct the movement of the vehicle, to support the vehicle load, and to transfer the load to the ground. It is the function of the guideway structure to endure applied loads from the vehicle and transfer them to the foundations. It is the main element in maglev system and holds big share of costs for the system. It is vital for maglev trains. The cost of the guideway structure is expected to be 60-80 percent of the overall initial capital investment cost (Zicha, 1986; Uher, 1989; Cai et al., 1994; FTA, 2004; Ren et al., 2009). Maglev train levitates over single or double track guideway. Guideway can be mounted either at-grade or elevated on columns and consists of individual steel or concrete beams. Elevated guideways occupy the least amount of land on the ground. Moreover, with such systems there is guarantee of meeting no obstacle while along the route. To guarantee safety for maglev trains necessitates guarantee that there will be no intersection between guideway and other forms of traffic routes. To serve the purpose, general proposition is to have elevated guideways.

Guideway provides guidance for the movement of the vehicle, to support the vehicle load, and to transfer the load to the ground. In maglev guideways contrary to traditional railroad tracks, there is no need to ballast, sleeper, rail pad and rail fastenings to stabilize the rail gauge. A guideway consists of a beam (girder) and two levitation (guidance) rails. Guideways can be constructed at grade (ground-level) or elevated including columns with concrete, steel or hybrid beams. Maglev elevated guideways minimize land occupation and prevent collision with other forms of traffic at-grade intersections. Guideways are designed and constructed as single or double tracks. Guideways can be U-shaped, I-shaped, T-shaped, Box, Truss and etc. Majority of cross-sections of guideway girders are also U-shaped. The rail gauges (track gauges) and spans are mostly 2.8 m and 24.8 m (Type I), respectively.

During the past three decades, different guideways have been developed, constructed and tested. Technical specifications of guideways for Federal Transit Administration (FTA) in U. S. Department of Transportation and TRI in Germany are presented in Table 3 (FTA, 2004, 2005a) and Table 4 (Schwindt, 2006), respectively. The guideway for the Transrapid in the Shanghai project was realized as a double-track guideway in 2001 and 2002. This Hybrid guideway is generation H2, type I as single-span (24.8 m) and two-span (2 x 24.8 m) girders. The Shanghai guideway I-shaped hybrid girder is 24.8m long, 2.8 wide, 2.2m high with a reinforced concrete girder (Schwindt, 2006; Dai, 2005).

Guideway consists of superstructures and substructures. Fig. 3 shows components of guideway's superstructures including beam and levitation (guidance) rails in an EMS maglev system where L is span length in meters and H is girder height in meters.

Depending on height of the guideway, it is separated in:

- At-grade guideway: $1.45 \leq h \leq 3.50$
- Elevated guideway: $h > 3.50$

Where h is guideway gradient height in meters.

The standard guideways are (Figs. 4, 5):

- Type I: L= 24.768 and $H \leq 2.50$
- Type II: L= 12.384 and $H \leq 1.60$
- Type III: L= 6.192 and plate construction, construction height ≤ 0.40

System	Guideway	Girder	Column	Span	Length of Span (m)	Cross-section	Width of Girder (m)	Height of Girder (m)
Magne Motion	Elevated	Concrete	Concrete	Two-span	36	Box	1	1.6
ODU [(a)]	Elevated	Concrete-Steel	Concrete	Single-span	25-27.5	Inverted-T	-	-
Colorado	Elevated	Concrete	Concrete	Single-span	25	U-shaped	-	-
Colorado	Elevated	Concrete-Steel	Concrete	Single/Two span	20 to 30	Box	2.972	3.66 (at mid-span) 5.49 (at the supports)
Colorado	Elevated	Steel	Concrete	Single-span	30	Truss	-	-
GA [(b)]	Elevated/ at-grade	Hybrid	Concrete	Single/Two span	36	Box	1.7	1.98, 1.22

(a) Old Dominion University
(b) General Atomics

Table 3. Technical specifications of guideways for FTA

No.	Guideway	Girder	Column (elevated)/ Support (at-grade)	Generation	Type	Span	Length of Span (m)	Year of Installation
1	Elevated	Concrete	Concrete	C 1	I	Single-span	24.8	1981-83
2	Elevated	Steel	Concrete	S 1	I	Single-span	24.8	1981-83
3	Elevated	Concrete	Concrete	C 2	I	Single-span	24.8	1984-86
4	Elevated	Steel	Concrete	S 2	I	Single-span	24.8	1984-86
5	Elevated	Steel	Concrete	S 4	I	Two-span	24.8	1995
6	Elevated	Concrete	Concrete	C 4	I	Single-span	24.8	1995
7	Elevated	Steel	Concrete	S 4	II	Two-span	12.4	1997
8	Ground-level (at-grade)	Steel	Concrete	S 4	II	Two-span	12.4	1997
9	Ground-level (at-grade)	Steel	Concrete	S 4	III	Two-span	6.2	1997
10	Elevated	Concrete	Concrete	-	I	Single-span	24.8	-
11	Ground-level (at-grade)	Concrete	Concrete	-	-	Two-span	-	-
12	Ground-level (at-grade)	Concrete	Concrete	C 4	III	Two-span	6.2	1998
13	Elevated	Hybrid	Concrete	H 1	I	Two-span	31	1999
14	Elevated	Hybrid	Concrete	H 2	I	Two-span	24.8	2001
15	Elevated	Hybrid	Concrete	H 2	I	Single-span	24.8	2002
16	Ground-level (at-grade)	Concrete	Concrete	C 5	II	Single-span	9.3	2005
17	Ground-level (at-grade)	Concrete	Concrete	C 8	III	Two-span	6.1	2006-2007
18	Ground-level (at-grade)	Hybrid	Concrete	H 3	II	Single-span	12.4	2006

Table 4. Technical specifications of guideways for TRI

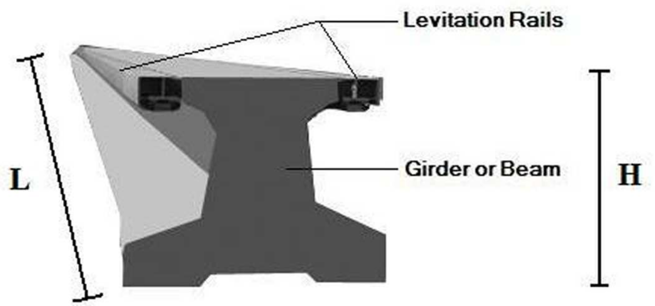

Fig. 3. Components of guideway in an EMS maglev system

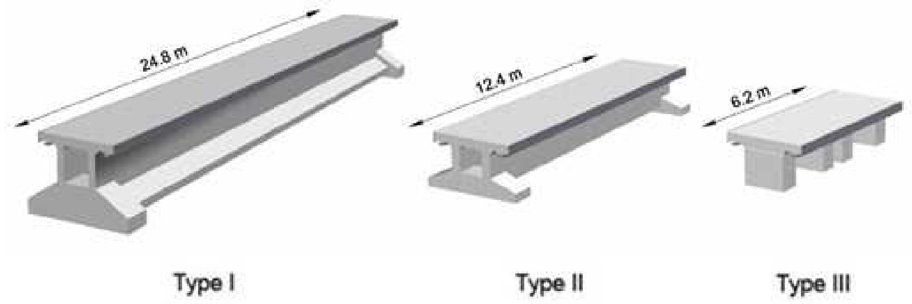

Fig. 4. Standard guideway types

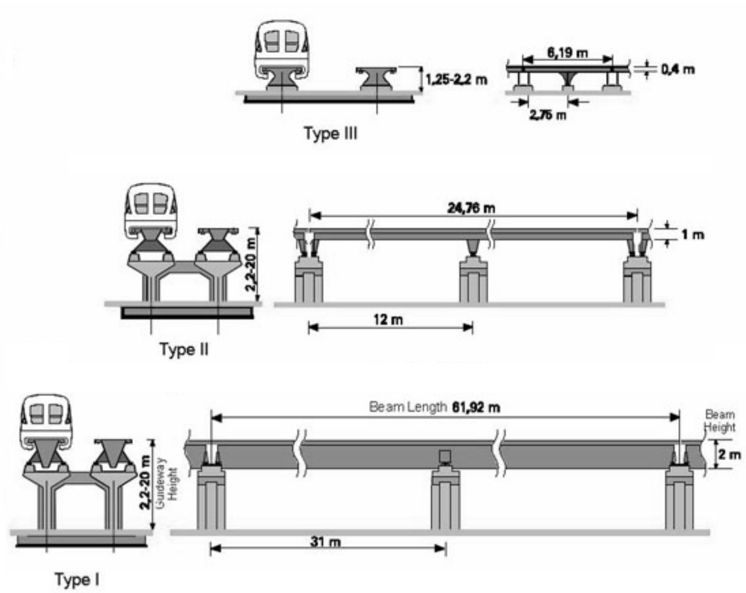

Fig. 5. Standard guideway types

The guideway height varies smoothly between 1.45 m and about 20 m. For greater guideway heights or span lengths larger than 40 m primary structures are needed in the form of conventional bridges. For substructures such as columns or foundations, reinforced concrete is proposed. The substructures for the guideway girders consist of several components. These are, depending on guideway type and gradient height, the column heads with bearing supports, the columns, tie beams and intermediate beams and the foundation slabs. They are built onto the natural soil, soil with soil improvement and/or on piles. The dimensions of the reinforced concrete substructures result from the high demands on the permissible deformations of the substructures (Grossert, 2006).

Different types of existing maglev magnetic suspension systems and technical specifications of existing guideways are presented in Table 5. As seen in this table, the majority of the maglev suspension systems are of electromagnetic suspension type. This table shows the most commonly used guideway structures and suspension systems. As indicated in the table, majority of guideway are elevated, double-track and U-shaped. The track gauges and spans are also mostly 2.8 m and 24.8 m, respectively.

Maglev systems	Shanghai China	Transrapid Germany	HSST Japan	JR Japan	U.S	Korea
Suspension	EMS	EMS	EMS	EDS	Different types (mostly EMS)	EMS
Section	I-shaped	Different Types (mostly U-shaped)	U-shaped	U-shaped Inverted T-shaped	U-shaped Box Truss	U-shaped
Track (rail) gauge	2.8 m	2.8 m	1.7 m	2.8 m	1-2.972 m	2.8 m
Guideway	Elevated	Elevated Ground-level (at grade)	Elevated	Elevated Ground-level (at grade)	Elevated	Elevated
Span length (elevated)	24.8 m	mostly 24.8 m	30 m	-	mostly 25 m	25-30 m
Maximum number of tracks in a route (guideway structure)	Double track	Double track	Double track	Double track	Double track	Double track
Maximum percent of tunnel in a route	0	22%	15%	87%	0	0

Table 5. Guideway structures and suspension systems

In recent years, different designs of guideways have been developed, constructed and tested among which U-girder guideways happens to be the most popular. In Korea, since 1980, prestressed concrete U-girder guideway for straight route applications has been proposed (Jin et al., 2007). In Germany, during 1981-1983, a U-girder guideway was built at the Transrapid Test Facility (TVE) by TRI and was used in the TR07 project (Lever, 1998). This guideway was further optimized and improved during 1984-1986 (Schwindt et al., 2007). An elevated concrete U-girder guideway was installed in TVE in 1995 (Schwindt, 2006). One of the three kinds of girders considered for Colorado Maglev Project (CMP) in the Colorado Department of Transportation (CDOT) is a concrete U-girder (FTA, 2004).

Frequent studies on the technical characteristics of beams shows that the following are among the reasons for frequent use of U-shaped cross-sections in majority of projects (Yaghoubi & Ziari, 2010):

- In general, in beams with closed cross-sections like box or U-shaped with continuous deck, the torsion is reduced. Also, structural continuity in cross-section reduces deflections due to vertical loads and possibly allow for higher speeds.
- The U-shaped beams have less deflection compared to other types of cross-sections.
- Cost of design, construction, installation and operation of U-shaped concrete beams compared to welded steel box girders and tubular steel space truss guideways is lower. Welding in steel box girders will cause a cost hike. Truss guideways also require many full penetration welds to insure the truss integrity under loadings, and this in turn would cause another cost hike.
- The continuity of the girder and the deck and the lack of need for installation of horizontal shear connectors between the concrete girder and the deck, in contrast to the railroad bridges.
- The U-shaped cross-sections are ideal as far as structural and strength (ultimate strength) are concerned.
- More centroidal moment of inertia and the section modulus of U-shaped cross-sections among cross-sections of equal sectional-area, including the I-shaped.
- Lower torsion of U-shaped cross-sections (as a closed cross-section) relative to other cross-sections including the I-shaped (as an open cross-section).
- Lower weight and volume (concrete used and lower dead load) of U-shaped cross-sections relative to other sections including the I-shaped.
- And generally, the U-shaped cross-sections are technically, operationally, economically, more satisfying.

It is geometrically simpler to design railway tracks without horizontal or vertical curves and without longitudinal or lateral inclinations. Practically, this does not happen very often. When tracks have to be laid in mountain ranges, engineers have to design horizontal and vertical curves and axial and lateral slops. While passing through horizontal curves centrifugal forces are added to other forces already present. Centrifugal forces are generated due to curves and tend to push the vehicle further away from the centre of the curve. The centrifugal forces also transmit efforts to the track pillars. In fact these forces are generated in the track and the main components to resist them are the track pillars. If the track or part of it is located in a horizontal curve, the effect of centrifugal forces needs to be included for the calculation proposes. These forces act horizontally and in a direction perpendicular to the tangent to horizontal axis of the track. Normally, track superelevation is added to the guideway to compensate these centrifugal forces. Regarding the structure, presence of centrifugal forces on the horizontal curves disturbs the balance of magnetic forces acting on the guideway. Therefore, it is necessary to make allowance for such effects when analyzing and designing for guideways on the curves. An important effect of introducing centrifugal forces on the horizontal curves is the unsymmetrical distribution of vertical loads on the guideway. This causes different calculation procedures for guideways on the curves compared to the straight routes.

The maglev can easily handle tight curves and steep grades of up to 10 %, resulting in fewer tunnels and other encroachment on the terrain (Siemens AG, 2006). The main task of route alignment is to stipulate the geometry of the guideway's function planes in such a way that the passenger enjoys maximum travel comfort when a vehicle travels on the guideway. Apart from acceleration, however, a consideration of changes in acceleration is also an important aspect of comfort. An exception to this is the track changing equipment, where, on the basis of the beam theory, the transition curve of the turnout position is also in the form of a clothoid in the horizontal plane. When route alignment, including determination of the spatial curve, is carried out, these or other aspects are taken into account, as well as the system's characteristics (Schwindt, 2006).

It is well known that torsion has particular significance on the curved bridges. A box section has a special advantage for a curved guideway because of its high torsion rigidity. A curved steel box girder guideway can provide longer curved spans with fewer supports than would be required for I girders, thereby creating greater cost savings in the substructure. For a given design speed and superelevation, the minimum radius of the circular portion of the horizontal curve may be determined based on either the passenger comfort criteria (lateral acceleration) or the vehicle stability criteria, depending on which criterion results on the smallest curve radius.

In the Colorado system, the passenger comfort criterion is based on the American Society of Civil Engineers (ASCE) People Mover standards. These standards provide a maximum recommended lateral acceleration on the passenger. The lateral acceleration is a function of the velocity and the radius of curvature. In addition to passenger comfort, the stability of the vehicle itself needs to be considered in the relationship between allowable curve radius and superelevation. Fabrication of the curved guideway sections is not widely discussed in maglev system literature. However, it is a central element of the guideway construction technique and can become a major consideration in the guideway cost (FTA, 2004).

When the vehicle travels on a straight piece of route, gravity is the most influential load acting on it. If the vehicle has geometrical symmetry and is loaded symmetrically, the gravity load passes through guideway axis of symmetry. When the vehicle travels on the curves, the centrifugal force will also be added to this effect.

Ideally, if there is adjustment for superelevation on the curve, loads exerted from vehicle to the guideway are symmetric and loading pattern will not be different from that of a straight route. However, on the curves with insufficient superelevation loading pattern will be different. While the principals of calculating the guideway loading on the curves and the straight routes are basically the same the main differences arise due to insufficient superelevation on the curves. This results in different amount of loads being applied to the guideway for both cases. Eccentricity caused by such effects, makes load on internal and external levitation rails different. It is clear that as a result of eccentricity due to insufficient superelevation the portion of load transmitted from vehicle to each one of the internal and external levitation rails will not be equal. It is vital for the guideway loading calculations to depict a proper pattern for its loading.

3.1 Loading

The most important part in the analysis and design of guideway is structural loading. The loading of the maglev vehicle is an important parameter in the practical application. It is related to the magnetic forces (He et al., 2009). The guideway must carry a dead load due to its own weight, and live loads including the vehicle loads. To incorporate the dynamic interaction between the guideway and the vehicle, the live load is multiplied by a dynamic amplification factor. Lateral and longitudinal loads including wind and earthquake loads may also need to be considered. The guideway loadings are modeled as dynamic and uniformly distributed magnetic forces to account for the dynamic coupling between the vehicle and the guideway. As maglev vehicle speeds increase to 300-500 km/h, the dynamic interactions between vehicle and guideway become an important problem and will play a dominant role in establishing vehicle suspension requirements. Magnetic forces are generated by the maglev vehicle and cause structural loading that transmits to the guideway. This can happen whilst such a vehicle is stationary or in motion. In order to prevent contact between the vehicle and the guideway and maintain the required gap between them, the system is continuously under Operation Control System (OCS) command.

Some decisive factors for the design of maglev guideways are listed as being constructible, durable, adaptable, reliable, readily maintained, being slim in accordance with urban environment and being light to be constructed more efficiently (Jin et al., 2007; Sandberg et al., 1996a, b). In this regard, one of the main challenges to guideway designers is to produce a structure that will be easily maintainable to the narrow tolerances and precise alignment required for practical high-speed maglev operation, to achieve a structure which is economically and financially justifiable and attractive (Plotkin at al., 1996a ,b). Besides satisfying the above conditions, important parameters in the design of guideway include vertical live loads and its pursuant dynamic amplification factors (DAF), plus deflection due to this load. These parameters constantly govern the design process, and they play a major determining role in the structural optimization of the guideway girder systems.

Vehicle/guideway interaction of the maglev system is an important and complicated problem. It is influenced by the levitation system, guideway structure, vehicle mechanical structure, running speed, etc. So the investigation of it should be launched out in many aspects (Wang et al., 2007). Among the various parameters which affect on design of maglev guideway, dead and live loads, dynamic amplification factor and deflection have major importance. Assessment of deflections due to the vertical loads for guideway beam during operation of maglev vehicle is very important. It is the most influential parameter in design of guideway (Lee et al., 2009).

While there are routine processes for the calculation of the guideway dead loading, there is a need for special treatment in the calculation of its live loads. Live load intensity and its distribution patterns are highly dependent on the structural behavior. According to AREMA (American Railway Engineering and Maintenance-of-Way Association) and UIC (International Union of Railways) regulations live load models for conventional railway track are based on a combination of concentrated and distributed loads. This is compatible with the use of wheels and the behavior of locomotives in conventional trains. In the case of trains with magnetic levitation with no wheels and added complexity of lifting magnetic forces due to support magnets, the analysis is much more complicated.

The forces are of attractive magnetic forces and can be categorized as lifting magnetic forces and lateral magnetic forces. The lateral magnetic forces include the restoring magnetic forces, the impact forces, etc. on the straight route and the restoring magnetic forces, the wind forces, the earthquake forces, the centrifugal forces, the impact forces, etc. on the curved route. Lateral magnetic forces due to interaction of the guideway and the guidance magnets ensure the lateral stability of the vehicle. Lateral guidance is provided by the configuration of the vehicle-guideway interface and by the levitation electromagnets. The "horseshoe" configurations of the electromagnet and levitation rails provide strong lateral restoring forces when perturbed from equilibrium (FTA, 2004). Guidance magnets are located on both sides along the entire length of the vehicle to keep the vehicle laterally stable during travel on the guideway. Electronic control systems assure the preset clearance.

The mechanical load at a specific point of the structure depends on its location within the car body, but not on the overall length of the vehicles or the position of the car body within the vehicle set. The interaction forces are the magnetic forces that can be derived from magnetic suspension models. Fig. 6 schematically presents locations for interactions between the vehicle and guideway. In this figure, (a) presents location for interaction between support magnets of the vehicle and the guideway levitation rail; (b) presents location for interaction between guidance magnets of the vehicle and guideway levitation rail.

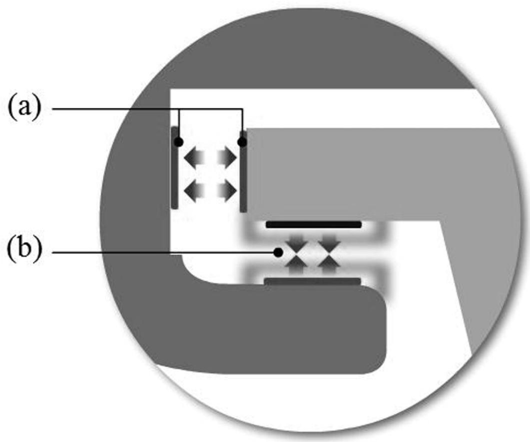

Fig. 6. Schematic of Interacting Maglev Vehicle and Guideway

Static (dead) load on the guideway generally consists of structural weight. It is important to remember that same type of guideway beams are selected for the straight and the curved routes. Even though, they may be selected with different types and shapes for the two types of routes (Jin et al., 2007).

3.1.1 Lifting magnetic forces (vertical loads)

Vertical loads imposed on maglev guideway can be categorized as dead loads due to the weight of the guideway divided by the length of the span, and live loads due to the interaction between guideway and the vehicle. Table 6 presents dead loads on guideways for some different maglev systems. Also, presented in this table, is the calculated dead loads on a railroad bridge.

Items	Span Length (m)	Girder Height (m)	Dead load (ton/m)
Urban Maglev Program, Korea (Jin et al., 2007)	25	1.51	2.948
	25	1.99	3.460
	25	1.402	2.68
	30	1.625	3.10
	25	1.515	2.95
	30	1.837	3.28
	25	1.794	3.16
	30	2.183	3.63
	25	1.991	3.46
	30	2.320	4.05
Linimo, Japan (Jin et al., 2007)	30	2.5	7.733
AGT, Korea (Jin et al., 2007)	30	1.92	5.531
Transrapid, Germany (Jin et al., 2007)	25	2.20	5.732
KIMM, Korea (Jin et al., 2007)	25	2.06	3.544
Expo Park Korea, Korea (Jin et al., 2007)	25	1.90	4.256
(Dai, 2005)	30	-	1.5[(a)], 3.5[(b)]
(Cai, et al., 1996)	-	-	1.82
Railroad Bridge [(c)]	18	1.45	14.8

(a) single-car maglev
(b) three-car maglev
(c) Consisting of four precast prestressed concrete girders of type 3 AASHTO.

Table 6. Dead loads on some typical maglev guideways

The magnetic force between the guideway and the supporting magnets causes the vehicle to levitate. The maglev guideway live loads consist of both static and dynamic loads. The static live load is the load due to the weight of the vehicle. In this case, the vehicle rests directly on the guideway. When the vehicle rises, an air gap appears between the vehicle and the guideway. The interaction force between the guideway and the i-th bogie in each car body is equal to $1/n_b$ of the total vehicle weight, including the car body (wagon), bogies, magnets and passengers. n_b is the number of bogies in each car body.

The movement of the vehicle over the guideway amplifies the static loads. Dynamic amplification factor (DAF) is a non-dimensional ratio of dynamic magnetic force to the static magnetic force. Incorporating a dynamic amplification factor, the dynamic lifting magnetic force between the guideway and the i-th bogie in each car body. DAF is the most influential parameter in design of guideway. The DAF of the guideway girder caused by the maglev vehicle is generally not severe compared with that caused by a traditional railway load, and is not significantly affected by vehicle speed. The effects of the deflection ratio and span continuity on the DAF of the guideway are negligible (Lee et al., 2009). DAF for variety of maglev systems is presented in Table 7. The DAF defined as the ratio of the maximum dynamic to the maximum static response of the guideway under the same load plus one, are used to evaluate the dynamic response of the guideway due to the moving vehicular loads.

In general, DAF is not a deterministic value and must be estimated through probabilistic methods. The amount of DAF depends on several parameters including the geometry of the guideway such as length of span, type of span (single-span or multi-span), etc.

<table>
<tr><th>Items</th><th>Span Length, L (m)</th><th>Maximum Speed (Km/h)</th><th colspan="2">Maximum DAF</th></tr>
<tr><td>Bechtel (Lever, 1998)</td><td>24.82</td><td>500</td><td colspan="2">1.4 (a)</td></tr>
<tr><td>TR07, Transrapid, Germany (Lever, 1998)</td><td>24.82</td><td>500</td><td colspan="2">1.56</td></tr>
<tr><td>Maglev Transit (Lever, 1998)</td><td>-</td><td>-</td><td colspan="2">1.4</td></tr>
<tr><td>Grumman (Lever, 1998)</td><td>27</td><td>500</td><td colspan="2">1.2</td></tr>
<tr><td>New (corrected) Grumman (Lever, 1998)</td><td>27</td><td>500</td><td colspan="2">1.36(b)</td></tr>
<tr><td>(Dai, 2005)</td><td>30</td><td>500</td><td colspan="2">1.37</td></tr>
<tr><td>UTM01, Korea (Yeo et al., 2008; Lee et al., 2009)</td><td>-</td><td>100</td><td colspan="2">1+15/(40+L)</td></tr>
<tr><td>Urban Maglev, Korea (Yeo et al., 2008)</td><td>25</td><td>110</td><td colspan="2">Steel girder: 1.15
Concrete girder: 1.1</td></tr>
<tr><td>Linimo, Japan (Yeo et al., 2008)</td><td>-</td><td>100</td><td colspan="2">Steel girder: 1.15
Concrete girder: 1.1</td></tr>
<tr><td>AASHTO LRFD Bridge Design Specifications (Dai, 2005)</td><td>-</td><td>-</td><td colspan="2">1.33(c)</td></tr>
<tr><td rowspan="6">Conventional Railroad Bridge (d)</td><td>5</td><td>-</td><td>δ_1=1.35</td><td>δ_2=1.53</td></tr>
<tr><td>10</td><td>-</td><td>δ_1=1.2</td><td>δ_2=1.31</td></tr>
<tr><td>15</td><td>-</td><td>δ_1=1.14</td><td>δ_2=1.21</td></tr>
<tr><td>20</td><td>-</td><td>δ_1=1.10</td><td>δ_2=1.16</td></tr>
<tr><td>25</td><td>-</td><td>δ_1=1.08</td><td>δ_2=1.125</td></tr>
<tr><td>30</td><td>-</td><td>δ_1=1.06</td><td>δ_2=1.09</td></tr>
<tr><td>General Atomics (FTA, 2005 a, b)</td><td>36</td><td>200</td><td colspan="2">1.5</td></tr>
</table>

(a) The Bechtel report indicates that this is a conservative value is used to design the girder (Lever, 1998).
(b) Calculated using diagrams of static vehicular loading and dynamic vehicular passage over guideway (Lever, 1998).
(c) In AASHTO LRFD Bridge Deign Specifications, the dynamic allowance (IM) for highway bridge design is 0.33 (the corresponding dynamic amplification factor is 1.33) (Dai, 2005).
(d) With track maintenance to accurate standards and criteria. δ_1: For Shear Force and δ_2: For Bending Moment.

Table 7. Dynamic Amplification Factor (DAF) for some typical maglev guideways

The interaction force (dynamic lifting magnetic force) between the i-th bogie in each car body and the guideway is transferred to two levitation rails. Due to the uniform distribution of the load on the levitation rails, the loading pattern on the guideway spans can be considered as a uniform distributed load.

The amount of live load of some different maglev systems are presented in Table 8.

Items	Span Length (m)	Live Load (ton/m)	Deflection Regulation (m)
Urban Maglev Program, Korea (Jin et al., 2007)	25	2.3	L/2000
	25	2.3	L/4000
Urban Maglev Program, Korea (Yeo et al., 2008)	25	2.6	L/2000
Linimo, Japan (Jin et al., 2007)	30	1.78	L/1500
Linimo, Japan (Yeo et al., 2008)	-	2.3	$20<L \le 25m$: L/1500 $25<L$: $(L/25)^{1/2} \times L/1500$
UTM01, Korea (Yeo et al., 2008)	-	2.2	L/4000
AGT, Korea (Jin et al., 2007)	30	-	L/1000
Transrapid, Germany (Jin et al., 2007)	25	2.4	L/4000
KIMM, Korea (Jin et al., 2007)	25	1.86	L/4000
Expo Park, Korea (Jin et al., 2007)	25	2.5	L/3000
CHSST, Japan (FTA, 2004)	30	2.3	-
Colorado, U.S. (FTA, 2004)	30	2.3	-
TR08, Transrapid, Germany (Schach et al., 2007)	-	2.2	-

Table 8. Live loads on some typical maglev guideways

In the static position or while maglev vehicle is resting on its guideway, the thickness of the air gap between vehicle and guideway is nil. Therefore, the total load of the vehicle weight will be transmitted to the guideway. As a result, the interaction force (total static lifting magnetic force of each car body) between each car body and the guideway is the static weight of the vehicle. Each car body is equipped with n_b bogies. Thus, the total interaction force between each car body and the guideway is the summation of interaction forces (static lifting magnetic forces) between the i-th bogie in each car body and the guideway. Maglev trains achieve a weight reduction in reaching the design speed (FTA, 2004).

As presented in Fig. 3, each guideway includes one beam (girder) and two levitation rails. Therefore, the total interaction force between each car body and each of the levitation rails, is equal to one-half of the total interaction force between each car body and the guideway. In other words, the interaction force between the i-th bogie in each car body and each of the levitation rails, is equal to one-half of the interaction force between the i-th bogie in each car body and the guideway. Dynamic magnetic lifting forces are the forces generated while the vehicle moves. The interaction force (total dynamic lifting magnetic force of each car body) between each car body and the guideway, is the sum of the interaction forces (dynamic lifting magnetic forces) between the i-th bogie in each car body and the guideway. Also, considering the fact that each guideway consists of two levitation rails, the interaction force between the i-th bogie in each car body and each of the levitation rails, is equal to one-half of the interaction force between the i-th bogie in each car body and the guideway. Interaction force between each bogie in each car body and the guideway is a uniformly distributed live load. Load uniformity comes from the absence of the wheels and presence of lifting magnetic forces with uniform intensity that is generated by support magnets. Interaction force between each bogie in each car body and each of the levitation rails is also uniformly distributed. If bogie lengths in each car body are the same, as normally is the case, then the total interaction force intensity between each car body and the guideway is equal to the interaction force intensity between the i-th bogie in each car body and the guideway over the length of bogie. Also, in such case, the total interaction force intensity between each car body and each of the levitation rails over the length of each car body is equal to the interaction force intensity between the i-th bogie in each car body and each of the levitation rails over the length of each bogie. Each maglev vehicle involves some (one to ten) car bodies with different lengths. Hence, maximum interaction force intensity between car bodies and the guideway can be considered as maglev live load. In general, maglev live loading is evenly and uniformly distributed. The amount of maglev live load is generally less than the dead load of its guideway. Also, the uniformly distributed live load of maglev applied to each levitation rail over the length of live loading.

3.1.2 Lateral magnetic forces (lateral loads)

In the static case, lateral (guidance) magnetic forces do not exist. However, during vehicle movements and while it moves to the sides, interaction of guidance magnets and levitation rails brings the vehicle back to its central stable position. This causes lateral magnetic forces. These lateral forces act in lateral and normal directions to the levitation rails and transmit to the guideway. When the vehicle deviates to the right, guidance magnets on the right side of horseshoe shaped section of the vehicle and levitation rail on the right side of guideway attract each other while guidance magnets on the left side of horseshoe shaped section of the vehicle and levitation rail on the left side of guideway repulse each other. This brings the vehicle back to its stable position. At the location of interaction between guidance magnets and levitation rails, forces in the left and right zones are of the same size and act on the same direction to the guideway.

One of the main advantages of the elevated transportation systems such as maglev is the high resistance of their tracks in dealing with the earthquake forces. Earthquake forces are included in the guideway design for Shanghai in China (Dai, 2005) and in Japan. There is no report of major earthquake in central Europe. Therefore, German Transrapid TR07 has ignored such effects, all together (Lever, 1998). Earthquake lateral forces imposed on maglev guideway are less than that of the railroad bridges.

Irregular earth movements generate such forces that can be capable of damaging the man made structures. The size of such forces depends on the nature of the earthquake, the natural period for the bridge structural vibrations and the natural period for vibrations of the soil under the foundation. For the design of the exceptional bridges with very large spans or for the bridges that are near the earth's fault lines, calculations for the earthquake forces depend on some detailed studies. One may use the static analysis for the design of small to medium size bridges. Dynamic bridge analysis however, needs huge number of calculations that are economically formidable and sometimes turn to be impossible. On the other hand, the quasi static approach uses a load (or an impact) factor that converts the dynamic loads into the static loads. Therefore, such method assumes static equilibrium when determining the structural behavior. The load (or the impact factor) comes from the experiences, engineering judgment and from mathematical models.

Guideways must endure the earthquake lateral forces in two perpendicular directions. They need to also transfer the lateral forces to the guideway foundations in both directions. These two directions normally include the guideway longitudinal axis and the direction perpendicular to it. The guideway columns must endure the earthquake forces caused by the guideway weight in addition to enduring the earthquake forces that are related to the columns weight. The later force comes from multiplying the earthquake factor by the weight of the columns. The earthquake factor is the same factor that is also used for the calculation of the earthquake force. For the calculation of the earthquake lateral force, if the size of the live load is less than half of the size of the deal load, the live load will be ignored. Otherwise, two third of the summation of the dead and live loads on the guideway needs to be accounted for. While calculating the earthquake lateral force for urban maglev guideways, at least half of the live load must be included.

Generally, the wind effect depends on the geographical position of the district, its altitude from the sea level, the local topography and to some geometrical characteristics. For the guideway static calculations, regardless from the number of the tracks the wind force affects only one maglev vehicle.

The interaction force (dynamic lateral magnetic force) between the i-th bogie in each car body and each of the levitation rails is defined by the summation of the interaction forces (dynamic lifting magnetic force) between the i-th bogie in each car body and each of the levitation rails and the wind or the earthquake lateral force, whichever that turns to be bigger. The earthquake lateral force also includes a DAF.

Lateral forces on the maglev guideway can be caused by the vehicle sliding, particularly on curves. Lateral guidance is provided by guidance magnets. The dynamic lateral magnetic force imposed on the guideway can be considered as a uniformly distributed load. Centrifugal forces, in equal speed and curve radius, are less in maglev due to lower weight of the vehicle than in rail tracks.

3.1.3 Longitudinal loads

In recent years, with increasing traveling speed of the rail systems, aerodynamic load problems became very important. From the system point of view, aerodynamical topics which affect and define the interface between rolling stock, infrastructure and operation are of paramount importance and the corresponding loads increase with the vehicle speed. If maglev vehicles pass in close proximity to each other or move close to fixed objects such as barriers or buildings, the aerodynamic interactions can produce significant loads on the vehicle or the fixed object. The magnitude and duration of the load depends on the velocity and geometry of the vehicles and also on the ambient wind speed and direction. For high-speed railroads several studies have examined the loads produced by passing trains and their potential for causing an accident. The results of these studies show an important pressure load acting on the object which can have serious consequences. The experiments were carried out on conventional railroad vehicles but from the system point of view, in principle, the aerodynamics of a maglev and a high-speed railroad system do not differ. Although the safety aspect does not concern the maglev vehicle as strongly as it concerns conventional railroads, because maglev is guided by magnets on both sides and cannot derail, many aspects are similar. In both cases, the interaction of vehicles and infrastructure implies aerodynamic system issues, e.g. that of train induced aerodynamic loads leading to structural vibrations and a decrease of ride comfort. The pressure load caused by passing maglev vehicles has an important aerodynamic effect on the sidewall motion and therefore on the ride comfort (Tielkes, 2006). While two vehicles are passing each other at high relative speed, the quasi-static pressure distribution along each vehicle presents a dynamic load on the other vehicle. The dynamic pressure load strongly depends on the velocity of the oncoming vehicle, the geometry of the bow-part of the oncoming vehicle and the distance between the two tracks. The time behavior is given by the relative velocity between the two vehicles. The mechanical load on the car body depends mainly on:

i. the amplitude of the pressure wave, given by
- the velocity of the oncoming vehicle
- the bow-shape of the oncoming vehicle
- the distance between the two tracks

ii. the relation between the propagation speed of the structural Eigenmode with the corresponding wavelength and the relative velocity between the two vehicles

iii. the load at a specific point of the structure depends on its location within the car body, but not on the overall length of the vehicles or the position of the carriage body within the vehicle set.

In general, the aerodynamic forces play an important role in affecting the interaction response of maglev-vehicle/guideway system due to their velocity-dependent characteristics, especially for the higher speeds over $600_{km/h}$ (Yau, 2009). Further development of the ground transport calls for solution variety of problems among which aerodynamic problems are very important. The up-date state of high-speed ground transport problem shows that the use of aerodynamic effects will make it possible to optimize the technical and economic performances of vehicles.

Longitudinal force can be applied to the guideway through braking and acceleration of the vehicle, vehicle weight when the guideway has a longitudinal slope, and air pressure (aerodynamics). Since maglev vehicles have no wheels, axles and transmission, they weigh less then a conventional railroad train. The lack of wheels also means that there is no friction between the vehicle and the guideway. These factors result in a reduction in energy consumption. Therefore, the vehicle requires a lesser force for braking and stopping it. For example, the attractive force due to braking in the Colorado maglev vehicle equals to 4.2-4.5 ton, which amounts to about 10% of its loaded vehicle mass of 44 ton (FTA, 2004). In conventional rail tracks, brake force is usually equal to 1/7 of the weight of the part of the train which is located on the bridge.

3.2 Analysis

During the past four decades, many maglev models have been proposed. In 1974, Katz proposed two simplified one dimensional maglev vehicle and suspension models. A simple two degree-of-freedom (DOF) vehicle system with one car body was used in his study (Katz et al., 1974). In 1993, Cai studied a multi-car vehicle model traversing on a guideway. Concentrated loads and distributed loads were compared. The coupled effects of vehicle and guideway interactions over a wide range of vehicle speeds with various vehicle and guideway parameters were investigated. Only vertical vehicle motion is considered in their study. A beam model with a uniform-cross-section was used. They found that a distributed load vehicle model was better than a concentrated load vehicle model which might result in vehicle accelerations in simulations. They concluded that multi-car vehicles had less car body acceleration than a single-car vehicle, because of the inter-car vertical constraints. However, a magnetic suspension model is not included in their study. The interface between the vehicle and the beam was modeled with an elastic spring and dashpot, which is not the case in a real maglev system (Cai et al., 1996). In 1995, Nagurka and Wang developed a dynamic maglev model which includes a five DOF vehicle model. The effects of the vehicle speed on the system performance were studied (Nagurka et al., 1997). In 2005, Huiguang Dai influenced by German TR08 maglev, defined a vehicle model, a magnetic suspension model and a beam roughness model. He studied dynamics of a single-car vehicle model with 4 bogies and a three-car vehicle model with 12 bogies. He used an elevated guideway with multiple concentrated moving loads. A total number of 500 simulations were performed to study the dynamic behavior of maglev vehicle and guideway beam (Dai, 2005).

Although extensive simulations and analyses have been performed, the development of design criteria for maglev guideways will require additional studies. Aerodynamic forces must be considered. Effects of horizontal curves should be considered. Maglev trains may be extended to 4 or more cars (Dai, 2005). Maglev vehicle/guideway interaction problem bothers the investigators and engineers for years. No well-accepted interpretation has been reported, yet. Vehicle/guideway interaction of the maglev system is an important and complicated problem. It is influenced by the levitation system, guideway structure, vehicle mechanical structure, running speed, etc. So the investigation of it should be launched out in many aspects (Wang et al., 2007).

During the past four decades, research and development have been performed in the areas of magnetic levitation, interaction of vehicle with guideway, and optimization of vehicle suspensions. The results of these efforts are useful in providing appropriate criteria for the design of maglev systems. The dynamic response of magnetically levitated vehicles is important because of safety, ride quality and system cost. As maglev vehicle speeds increase to 300-500$_{km/h}$ the dynamic interactions between vehicle and guideway become an important problem and will play a dominant role in establishing vehicle suspension requirements. Different dynamic responses of coupled vehicle/guideway systems may be observed, including periodic oscillation, random vibration, dynamic instability, chaotic motion, parametric resonance, combination resonance, and transient response. To design a proper vehicle model that provides acceptable ride quality, the dynamic interaction of vehicles and guideways must be understood. The coupled vehicle/guideway dynamics are the link between the guideway and the other maglev components. Thus, reliable analytical and simulation techniques are needed in the design of vehicle/guideway systems. Furthermore, a coupled vehicle/guideway dynamic model with multiple cars must be developed to meet system design requirements.

For a dynamic analysis of vehicle/guideway interactions, an understanding of the effects of distributed loads is essential. The maglev vehicle is the source of magnetic forces and loading starts from this vehicle. These forces transfer to the guideway while the vehicle is stopped or when it moves. Each car body model can be considered as a uniform rigid mass. It is supported by two to eight springs and two to eight dashpots that form the secondary suspension for maglev vehicle. The primary suspension consists of two to eight magnetically supported bogies. Maglev vehicle can be single-car or multiple-car.

Magnetic levitation is caused by magnetic forces that transmit to guideway by maglev vehicle. In fact, these forces are the consequence of interactions between vehicle and guideway caused by magnets. For EMS systems, these magnets are installed within the vehicle. The forces are of attractive magnetic forces. Lifting magnetic forces due to interaction of guideway and support magnets cause the levitation of the vehicle. Support magnets are located on both sides along the entire length of the vehicle. The attractive force produces inherently unstable vehicle support because the attractive force increases as the vehicle/guideway gap decreases.

The interaction forces are the magnetic forces that can be derived from magnetic suspension models. Static load on guideway generally consists of the vehcile weight. In either case, the dead load is uniformly distributed along the full length of the beam. Calculations of live load need more attention. Dynamic lifting forces are derived from static lifting forces. Therefore, accuracy of these models is vital to the accuracy of live load models. Combination of these models plus the live load models leads to the analysis and design of guideway. In static position or while maglev vehicle is resting on its guideway, thickness of the air gap between vehicle and guideway is nil. Therefore, total load of vehicle weight will be transmitted to the guideway. As a result, the interaction force (total static lifting magnetic force of each car body) between each car body and the guideway is the static weight of the vehicle. Each car body is equipped with n_b bogies. Thus, the total interaction force is summation of interaction forces (static lifting magnetic forces) between the i-th bogie in each car body and the guideway. Interaction force (dynamic lifting magnetic force) between each bogie in each car body and the guideway is a uniformly distributed live load. Load uniformity comes from absence of the wheels and presence of lifting magnetic forces with uniform intensity that is generated by support magnets. Maglev live loading is evenly and uniformly distributed. Amount of maglev live load is generally less than dead load of its guideway.

These forces transfer to the guideway while the vehicle is stopped or when it moves. Each car body model can be considered as a uniform rigid mass. It is supported by two to eight springs and two to eight dashpots that form the secondary suspension for maglev vehicle. The primary suspension consists of two to eight magnetically supported bogies. The electromagnets are mounted on the rigid bogies and generate attractive magnetic forces while interacting with ferromagnetic stator packs. Connections between magnets and bogies are assumed to be rigid. Two dimensional motions of the vehicle include heave motion and rotational motion. Maglev vehicle can be single-car or multiple-car. For example, a single-car vehicle with four bogies has 6 DOF including one translational and one rotational displacement at the center of mass of the car body, and one translational displacement for each of the four bogies. By the same token, a three-car vehicle with four bogies in each car body has 18 DOF. A dynamic simulation for maglev vehicle/guideway interaction is essential to optimize the vehicle design.

A variety of these parameters are presented in Table 9 for different types of maglev systems.

Maglev System/ Model	General Atomics (GA), U.S. (FTA, 2005a, b)	Old Dominion Uni. (ODU), U.S. (FTA, 2005)	(Wang et al., 1997)	(Cai et al., 1996)	TR08, German (Schach et al., 2007)	Shanghai, China (Guangwei et al., 2007)	(Dai, 2005)	HSST-100L, Japan (FTA, 2005b)	CHSST, Japan (FTA, 2002, 2004)	Colorado, U.S. (FTA, 2002, 2004)
Number of car body in the vehicle	1	1	1	3	5	5	3	2	2	2
Length of each car body, in meters	13	13.7	18	25	24.8	24.8	24	15	24.38	24.38
Number of bogies in each car body	2	2	2	8	4	4	4	5	5	5

Table 9. Parameters of some maglev vehicles

3.3 Design

Guideways are designed and constructed with concrete or steel girders. Concrete guideway girders can be as reinforced or prestressed. Guideway girder is evaluated for different load cases. As example, the Shanghai guideway girder was evaluated with respect to as many as 14,000 load cases by consideration of the deflection, dynamic strength and thermal expansion. The guideway girder for Urban Maglev Program in Korea was also evaluated for five load cases that are combinations of the dead load, live load and the prestressing forces of the tendon (Jin et al., 2007).

Guideways are usually made as single-span or two-span elevated or at-grade. But for larger spans the use of continuous two span supports is recommended. This can reduce deflection and the effect of temperature variations (FTA, 2004). Guideways are modeled as a single or multi span beam with uniformly distributed dead and live loads. Analyses are aimed at obtaining maximum stresses and deflections in guideway spans. The design criteria have deflection regulation on live load and concrete strength condition on top and bottom ends of the girder. The design criteria of the maglev guideway can be summarized as the deflection regulations due to live load in the sense of serviceability and the stresses limits of the girder due to the combination of the dead load and live load. Any classical beam analysis or finite element methods can be adapted in order to obtain maximum stresses and deflections of the beams. Design methods of guideway beam should satisfy the design criteria regarding loading conditions (live load and dead load) and deflection conditions due to live load. The stresses are controlled according to regulations such as AREMA or AASHTO specifications. As example (Jin et al., 2007), the allowable stresses for prestressed concrete compressive strength f_{ck} are described in Table 10.

Parameter	Description	Unit
Compressive strength at initial prestressing	$0.8f_{ck}$	MPa
Compressive strength just after prestressing	$0.55f_{ci}'$	MPa
Tensile strength just after prestressing	$0.75\sqrt{f_{ci}'}$	MPa
Compressive strength under design load	$0.4f_{ci}'$	MPa
Tensile strength under design load	$1.50\sqrt{f_{ci}'}$	MPa

Table 10. Allowable stresses of concrete guideway girder

Till now, variety of design methods has already been used. The Allowable Stress Method was used for design of GA maglev system foundations in U.S (FTA, 2005b) and the Urban Maglev Program in Korea (Jin et al., 2007). The AASHTO Standard Specifications for Highway Bridges were used for design of the Colorado maglev system in U.S (FTA, 2004), the maglev system of GA in U.S (FTA, 2005b) and Transrapid TR08 maglev system in German (Dai, 2005). The AREMA Standard Specifications were used for design of the tensile stress in prestressed concrete for the maglev systems of Colorado in U.S and CHSST in Japan (FTA, 2004). The Service Load Design Method was used for preliminary design of the Colorado special guideway to obtain a reasonable proportioning of members and for estimating material quantities (FTA, 2004).

The maximum allowable total deformation of the guideway can come from the settlements caused by consolidation or creep, by dead load, by cyclic loads from the vehicles or by dynamic loads during operation. Due to the importance of the geometry deviation in the serviceability and safety of the maglev guideway, tighter control over the deflection due to live load is required. In other words, there should be very strict limit adopted for the deflection in order to provide the required serviceability and safe parathion. Main contributors to guideway beam deflection is its' live load. Deflection due to dead load of guideway beam is usually very small and time-dependant. The maglev systems of CHSST and Colorado are no exceptions (FTA, 2002, 2004).

Lower deflection in guideway brings the possibility of reaching at higher speeds of travel. Structural continuity, reduction in span length, reductions in live load and DAF, load combinations, much concrete characteristics compressive strength, use of prestressed concrete, section modulus and etc. are among effective factors in the reduction of the deflection due to the live load. In general, utilization of prestressed concrete, increase of required concrete compressive strength and modules of elasticity reduces guideway beam deflection.

Structural continuity reduces live load and dead load deflections and possibly allow for higher speeds. Deformations due to creep and joint bearing costs also reduce with the use of structural continuity. Over time, precast girders get considerable variation in cambers and early creeps, but very little time deflection after continuity and composite behavior is achieved. The design with AREMA specifications results in the relatively high live load to total load ratio combined in comparison to other load combinations (because of the high effect of this type of load). It should be noted that this loading combination in comparison to other regulations consist of the highest load factors (LF), and at the same time the current regulation scheme with the use of the allowed tensile stresses applies a more accurate control over the deflection due to live load (FTA, 2004).

Up till now, different proposed regulations for deflection ratios due to live load such as L/500, L/1000, L/1500, L/1750, L/2000, L/2500, L/3000, and L/4000 have been proposed. In the Transrapid maglev systems generally beams are designed for the deflection ratios due to live load of L/4000 which is the optimum in design terms and in terms of economic efficiency (Jin et al., 2007; Lever, 1998; Schwindt, 2006). The allowable deflection ratios due to live load of some different maglev systems, a high-speed railway and conventional railroad bridges are presented in Table 11 where L is the span length.

Items	Span Length (m)	Dynamic Deflection Regulation (m)
Korea(a) (Jin et al., 2007)	25	L/1500
	30	L/1500
	25	L/2000
	30	L/2000
	25	L/3000
	30	L/3000
	25	L/4000
	30	L/4000
Proposed Girders[(b)] (Jin et al., 2007)	25	L/2000
	25	L/4000
A Proposed Girder[(c)] (Yeo et al., 2008)	25	L/2000
Linimo, Japan (Jin et al., 2007)	30	L/1500
Linimo, Japan (Yeo et al., 2008)	-	20<L ≤ 25m : L/1500 25<L : $(L/25)^{1/2}$×L/1500
AGT, Korea (Jin et al., 2007)	30	L/1000
Transrapid, Germany (Jin et al., 2007)	25	L/4000
KIMM, Korea (Jin et al., 2007)	25	L/4000
Expo Park, Korea (Jin et al., 2007)	25	L/3000
UTM01, Korea (Yeo et al., 2008)	-	L/4000
TGV[(d)] -Atlantique (Lever, 1998)	-	L/4000
TR07 (Lever, 1998)	25	L/4000
Bechtel (Lever, 1998)	25	L/2500
Foster-Miller (Lever, 1998)	27	L/2300
Grumman (Lever, 1998)	27	L/2500
Magneplane (Lever, 1998)	9.1	L/2000
Colorado, U.S. (FTA, 2004)	30	L/1750
CHSST, Japan (FTA, 2004)	30	L/1750
(Dai, 2005)	30	L/4000
Railroad Bridge	-	L/800

(a) Structural optimization results of Korea guideway girder systems
(b) Two types of proposed U-type girder systems for Urban Maglev Program in Korea (Jin et al., 2007)
(c) A proposed U-type girder system for Urban Maglev Program in Korea (Yeo et al., 2008).
(d) The French Train a Grand Vitesse (a high-speed railway train)

Table 11. Allowable deflection due to live load for some typical maglev systems

4. Station

Stations have emerged as a new central place in metropolitan cities and have become hub of networks due to their high accessibility by different modes of transport in high scale level. Furthermore, they produce movements which offer sufficient opportunity for the development of commercial land use. Railway stations entered a new age again in the late 20th century after the introduction of high-speed trains. Stations play a very important and influential role in the maglev transport system. The efficacy of the maglev system over the national and regional development depends on the stations. The development hub of maglev system mainly formed around stations.

Transportation facilities are both collectors and distributors. The overall goal of these transit stations is to collect and distribute as many passengers as possible with a minimum amount of confusion and inconvenience. Stations should have the capacity to accommodate large concentrations of passengers at various times throughout the day. The stations activities consist of everything from passenger service to the maintenance of the building. It is important to provide the traveler with a pleasant experience and atmosphere that will hopefully lead to repeat business in the future. The station should be able to provide for all of the modern conveniences to better serve the employees as well as the weary travelers. The important idea is to be able to get the people to their next destination as quickly as possible, and if a wait happens to occur then the station should be equipped to accommodate the passengers' needs (Stone, 1994).

Maglev stations are key regional transportation facilities designed to provide access for high volumes of passengers. The Maglev stations will provide regional and local intermodal connections, as well as national and international connections to passenger facilities. The aesthetic features of the stations are intended to reflect the intrinsic values of the Maglev system: advanced technology, movement, and speed. The conceptual design calls for open-air stations with natural light and ventilation.

Fundamentally, a maglev station is equivalent in planning, design, and operation to an inter-city or commuter railroad station. There is only one technical aspect of maglev that constrains station design: unlike railroad tracks, the maglev guideway cannot be crossed by passengers and vehicles at grade. As a result, maglev station designs must provide grade-separated passenger access to the station platforms. This form of access requires "vertical circulation" (stairs, elevators, escalators) to connect the platforms with tunnels under or bridges over the tracks. Stations should provide the proper functions of typical transit stations, including platforms, Shelter, Vertical and Horizontal circulation, Amenities and Services, Climate controlled waiting room, Public restrooms, Snack service, Public telephones, Changeable message display, Safety. All the station designs are planned to be consistent with the character of the buildings in the area of operation or predicated on the community standards of the local area where each station is located. The station must support the safe movement of passengers at specified flow rates and must also support particular levels of vehicle traffic. Based on the patron markets the following elements, features, and design standards should be common to all maglev system stations, regardless of location or patronage volumes. The expression of these standards will vary and additional features may be added, depending on station location.

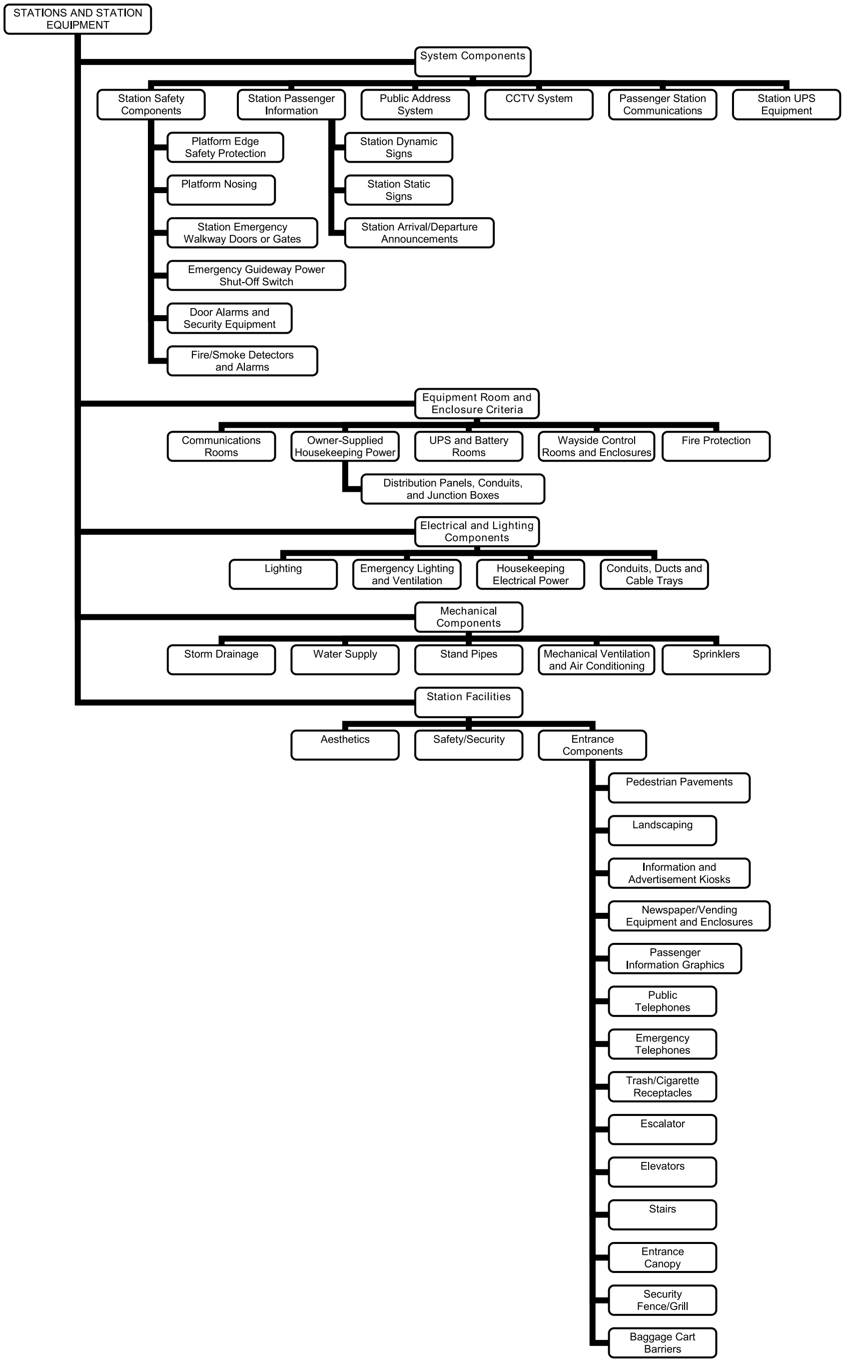

Fig. 7. Maglev station equipment

Platforms will be elevated, allowing direct access through train doors without steps or ramps. No free passenger access to the guideway will be permitted, for safety reasons. This is mandatory due to the speed and low noise profile of maglev systems. The use of docks and in-station transfer switches means that passing trains, while not necessarily in close proximity to platforms, could injure anyone who strayed into the active main guideway. For vertical circulation all maglev system stations will provide escalators and elevators as the primary elements and stairs as the backup.

The station services, including public rest rooms, snack service, newsstand, staffed ticketing and information center, and public telephones should be provided. Stations should also provide facilities (shops, changing rooms, luggage storage, etc.), access to traveler services such as station cars, and advertising displays. All stations would feature public art appropriate to their locations. Public art is an excellent adjunct to station design and a popular feature. Train and station operations require the station personnel and security. Station managers and ticket agents control the station activities, providing passenger assistance and information as well as inspecting train sets when in station. Armed security personnel are provided at every station. Large stations have multiple security personnel, and parking garages are policed (FTA, 2004).

5. Operation

5.1 Performance

The most important task or essential aim when designing the alignment is to specify the geometry of the guideway's functional planes so that the passenger traveling in the vehicle on the guideway experiences optimum comfort during the journey. The geometry defines the limit values for accelerations in the three spatial directions (X, Y, and Z direction). However, apart from the acceleration, the consideration of the change in acceleration (jerk) is also an important aspect for comfort. Therefore, various mathematical formulae were discussed for the transition curves and lengths, with the result,

- the horizontal transition curves are designed as sinusoidal curves and
- the vertical transition curves are designed as clothoids.

An exception are the track switching devices which, based on beam theory, are also designed using clothoids for the horizontal transition curves in the turn-out position. The alignment is designed and the space curve established taking into consideration the aspects given above as well as the system characteristics, e.g.

- climbing capability up to 10% and
- cant (superelevation) in curves up to 12%.

The space curve data are used in the next design phase as the design criteria for

- specifying the substructures,
- height of the columns,
- geometry of each individual beam,
- location of the track switching devices and for the
- precise location of the functional components on the beam (Schwindt et al., 2004).

The reductions in speed in the track course result from slopes, where the residual acceleration abilities do not maintain a high speed. Based on faster acceleration, the operation speed of the maglev can be smaller than that of the ICE3 in order to achieve the same running time. The primary energy demand that is relevant for the comparison between different means of transport averages under the examination of the current power mix as 2.5 times the secondary needs (Witt et al., 2004).

5.2 Propulsion system

Electronic control systems control the clearance (nominally 10 mm). The levitation system uses on-board batteries that are independent of the propulsion system. The vehicle is capable of hovering up to one hour without external energy. While traveling, the on-board batteries are recharged by linear generators integrated into the support magnets.

A synchronous, long stator linear motor is used in the Transrapid maglev system both for propulsion and braking. It functions like a rotating electric motor whose stator is cut open and stretched along under the guideway. Inside the motor windings, alternating current is generating a magnetic traveling field that moves the vehicle without contact. The support magnets in the vehicle function as the excitation portion (rotor). The speed can be continuously regulated by varying the frequency of the alternating current. If the direction of the traveling field is reversed, the motor becomes a generator which brakes the vehicle without any contact.

In accordance with Lenz's Law, the interaction of the levitation field with the current in the slots of the rail results in propulsion or braking force. During the motion of the magnet along the rail, the linear generator winding of the main pole is coupled with a non-constant flux, which induces a voltage and reloads the on-board batteries. The generation process begins in the range of 15 km/h and equals the losses of the magnetic suspension systems at 90 km/h. The whole energy losses of the vehicle are compensated at a velocity of 110 km/h and the batteries are reloaded. Thus the levitation magnet integrates three tasks: levitation, propulsion and transfer of energy to the vehicle (Dai, 2005).

The superhigh-speed Transrapid magnetic levitation system is powered by a synchronous, ironcored long stator linear motor which – in contrast to the classic railroad – is not installed on board the vehicle but in the guideway along the route. The special features of the long stator linear propulsion system enable its dimensions to be individually adapted to the running requirements of the route as well as to specific operating concepts.

The structure of the propulsion system developed for revenue service comprises a number of components, which are located along the guideway. These drive components are temporarily switched together to form the propulsion units necessary to permit maglev operation over the guideway. A propulsion unit remains in the switched configuration for as long as a vehicle is operating within the corresponding control range (drive control zone). It is capable of driving, accelerating and retarding one maglev train. A prolusion unit comprises the line section itself and, depending on the type of power supply selected, one or two propulsion blocks. The propulsion blocks are housed in substations, the latter being situated beside the guideway and spaced at a maximum distance of 50 kilometers. A substation for a single guideway contains one or two propulsion blocks, the necessary power supply and the decentralized operations control equipment (Fig. 8). A substation for a dual guideway simply is composed of two single-guideway substations.

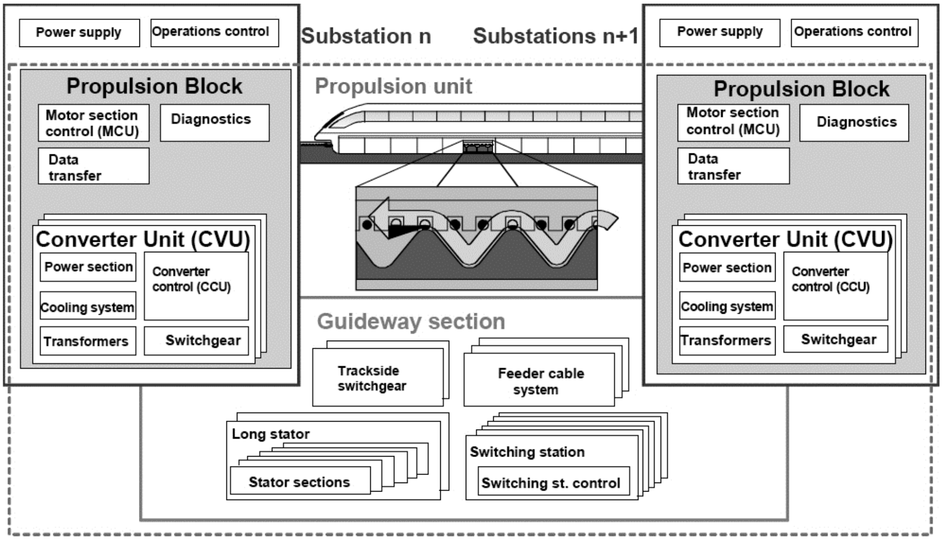

Fig. 8. Structure of the propulsion system

A guideway section consists of two long stators, each comprising the necessary stator sections and switching stations to cover a distance of up to 50 km, the feeder cable systems (two or three according to the selected mode of stator section switching) and the trackside switchgear. A propulsion block is made up of the converter units as well as the motor section control, diagnostics, and components of the data transfer system. In turn, one converter unit comprises a converter power section, rectifier- and output transformers, a closed-loop/open-loop converter control system, a converter cooling system and converter switchgear.

In a double-end feeding configuration, power is supplied to both ends of a guideway section from the two propulsion blocks of adjacent substations. If each substation has only one propulsion block per guideway, there must be at least one clear drive control zone between two maglev vehicles running in the same direction. However, if each substation has two propulsion blocks per guideway, the second maglev vehicle may enter a zone just cleared by the first. Data exchange between the components of a drive control zone as well as between adjacent control zones and external subsystems is made possible by a powerful data transfer system (Henning et al., 2004).

Propulsion in the maglev system is achieved by a linear synchronous motor (LSM). The linear synchronous motor comprises three-phase stator windings mounted on the underside of the guideway and producing a traveling magnetic field BS (its velocity being proportional to the frequency of the input signal) along the guideway. The second component of the LSM is the onboard excitation system. The excitation system made of the levitation electromagnets produces an excitation magnetic field BR. Propulsion is achieved when the excitation magnetic field BR synchronizes and locks to the travelling magnetic field BS. As a consequence, the speed of the vehicle is proportional to the input frequency of the three-phase stator windings.

The task of the power supply system is to supply all components of the Transrapid system with the demanded power. The main consumer naturally is the propulsion system; others are the power rail supply for the on-board supply of the vehicle, the auxiliary power supply for the propulsion control system as well as the operation control system, the guideway switches and the reactive power compensation.

The components of the Power supply system (PS) are installed in substations – where the main components of the propulsion system and the decentralized operation control system are installed, too – and in transformer stations, which are both located along the guideway. The distance between the substations and transformer stations mainly depends on the characteristic data of the operating program and system layout, such as speedtime-diagramm, minimum interval between maglev vehicles, stations, and auxiliary stopping areas. Furthermore, the availability of the power supply system is a very important stipulation for the power supply system layout.

The propulsion system and power supply for Shanghai Maglev Transrapid Project is based on the structures described above and is designed according to the requirements of the transportation system. The main requirements for a transportation system are:

- track length
- passenger capacity
- travel time to destination
- maximum waiting time for passengers at the stations

Therefore the main design parameters for a transportation system are:

- alignment
- comfort criteria
- speed profiles
- operation concept including headway times
- availability, reliability

In relation to these parameters and the necessary input data

- number of vehicles and number of sections per vehicle
- vehicle data, e.g. aerodynamic resistance
- comfort criterias, e.g. max acceleration, max. jerk
- restrictions regarding size or location of power supply or propulsion equipment the propulsion system and power supply was designed (Hellinger et al., 2002).

5.3 Optimal design speed

The optimal design speed of transportation project relates not only to the national integrated transportation system structure, but also to the energy consumption structure of national economy and the traveling quality of passengers. Starting from the analysis to technical and economical characteristics of the maglev system, this paper tries to find the optimal design speed of high-speed maglev transportation system in different aspects such as the speed structure of integrated transportation system and the project benefit. As a result, it gives reference to the planning of high-speed maglev transportation project.

The determination of the design speed is a strategic decision-making for a transportation model. It relates to the compatibility with social economic development. The design speed of a transportation model has remarkable influence on its construction and operation cost, the ability of its competition in transportation system, then its survivability further. The design speed of high-speed transportation system is a basic precondition for its line-planning, developing and manufacturing of vehicles and other equipments, forecast of the market demand, the assessment of economical and social benefit. It is the most important parameter to develop a high-speed transportation system.

The maximum operating speed the train may be raised step by step along with the market demand and the technical development. Therefore, the optimal design speed of mobile equipment of a project should be considered according to the conditions in the near and far future.

The commercial service speed refers to actual operating speed of the train under synthetic consideration of the market demand and economic benefit of the project. It can be determined according to many factors such as the function of a project in the whole transportation system, the competitive ability, the operating cost, the ticket price, the paying ability and the payment wish of passenger and so on. To adapt the market demand and obtain the best economic benefit, including national economic benefit and social benefit, is the principle to determinate the commercial service speed. Along with the development of economy and society, the best commercial service speed will therefore change. Therefore, in different period there is different optimal commercial service speed.

The optimal design speed of infrastructure will be affected by the natural conditions; The optimal commercial service speed will be affected by the social and economic environment; The optimal design speed of mobile equipments will be affected by the related industry technical level.

The following points should be taken into account:

1. The technologically suitable speed range of high-speed maglev system;
2. The best speed to improve the speed structure of integrated transportation system;
3. The requirement on travel speed of passenger;
4. The influence to the optimal design speed for a certain project situation, such as the line length or travel distance, the local economic development level and the natural conditions (Wanming et al., 2006).

5.4 Transrapid propulsion system

The propulsion system structure meets all the requirements for commercial operation in Shanghai, such as a modular design, high reliability, high availability as well as low maintenance expenditure. The outstanding advantage of the modular structure introduced is that individual components can be replaced in accordance with project requirements without affecting the rest of the system. For example, three different converter power sections are being used in the Shanghai project in order to adapt the converter output to the route's particular requirements regarding acceleration and speed. The double-track route is 30 km long. Consequently, at a maximum operating speed of 430 km/h, the travel time is only 7.5 minutes. Three 5-section maglev vehicles operate in round-trip mode at intervals of

10 minutes. The propulsion and power supply system has been specially configured for this service frequency. Although SMT is only 30km long, the test results show it has excellent characteristics of power-energy consumption/speed and it is the best tool for long distance transportation.

6. Safety and risk assesment

6.1 Safety concept

Despite high speeds, passengers are safer in maglev vehicles than in other transportation systems. The electromagnetically suspended vehicle is wrapped around the guideway and therefore virtually impossible to derail. Elevated guideways ensure that no obstacles can be in the way (Dai, 2005). Maglev systems are required by law to guarantee construction and operation of a system that meets proper safety standards. The responsibility of maglev systems are schematically shown in Fig. 9.

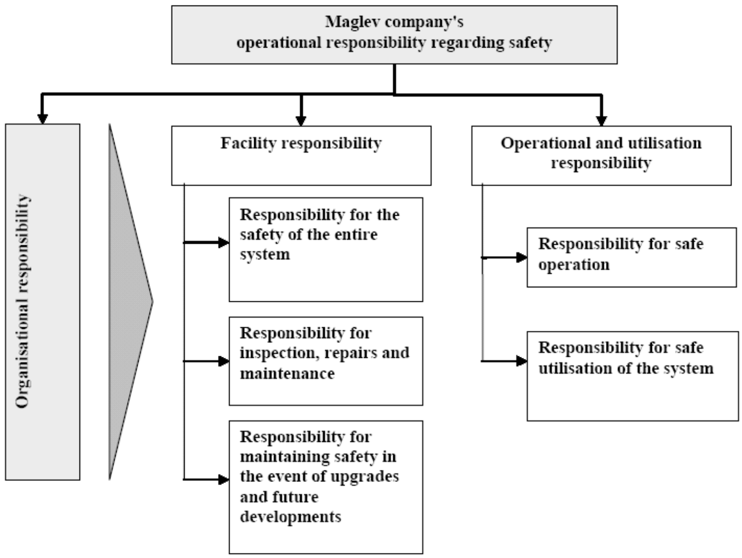

Fig. 9. Maglev system's responsibility

The requirements resulting from safety concepts have effects on all system components and on the whole planning and approval process. Certain internal and external dangers, which affect a maglev system installation, may only be limited regarding their risk potential through constructional measures.

6.2 Rescue concept

An essential component of the safety concept is the rescue concept. The maglev vehicle operator has to explain in this concept with which measures self and external rescue shall be guaranteed. Depending on conception self and/or external rescue measures require different sizes of escape routes, places for emergency stops and accessibilities. Therefore, the rescue concept influences the extent of the required properties so that the effects on the planning approval procedure are given immediately. The examples of protection against going off and rescue concept clearly show how safety concept and planning approval are connected with each other. This means that the development of a safety concept must be at the beginning of the planning process of a maglev system. However, changes of the route course may occur because of others than for safety reasons, so that corresponding customizations of the safety concept can become necessary at a later date.

The factors affecting transportation safety and security are various, among which, the physical structure and guideway security patrols play significant roles. Elevated guideways can be operated safety and efficiently (Liu & Deng, 2003). A means will be required to transfer passengers from the emergency walkway to the ground unless rescue vehicles are used to remove passengers from the walkway. The proposed method of egress from the emergency walkway is a pair of hinged stairways located within one guideway span where the walkway beam would be discontinuous. The stairways would be hinged at the end of the walkway beam and would be attached to dampers that would control the lowering of the stair. The passengers would need to activate a manual release mechanism and then the stair would lower by gravity, slowed by the dampers. The stairways would need to be located at intervals that are a reasonable walking distance. An interval of 0.40 kilometers has been assumed for cost estimating purposes. Signs would be mounted on the emergency walkway that direct passengers to the stairways and indicate the distance from their present location. Figs. 10 to 13 and Fig. 14 show required facilities while emergency situations for Colorado maglev project in the Colorado Department of Transportation (CDOT), U.S. and MOCIE maglev project in the Ministry of Commerce, Industry & Energy of Korean Government (MOCIE), respectively (FTA, 2004, 2005a).

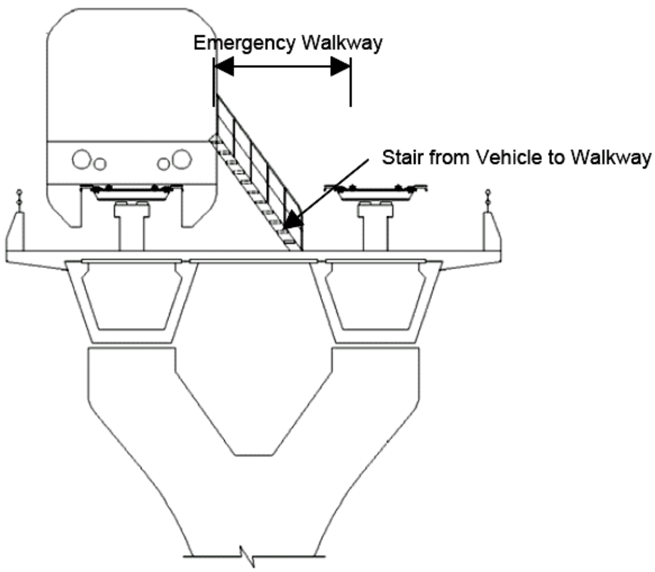

Fig. 10. Double-track guideway

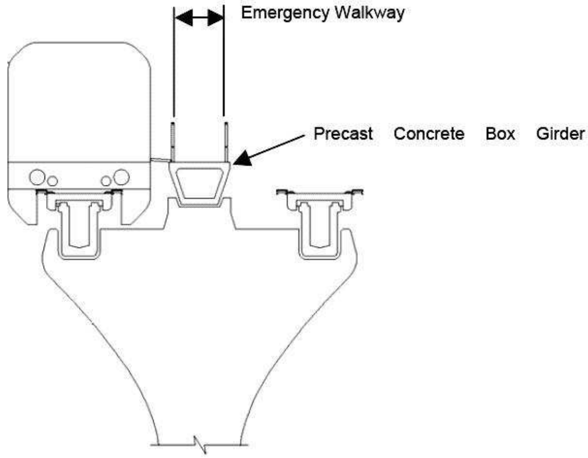

Fig. 11. Separated walkway beam

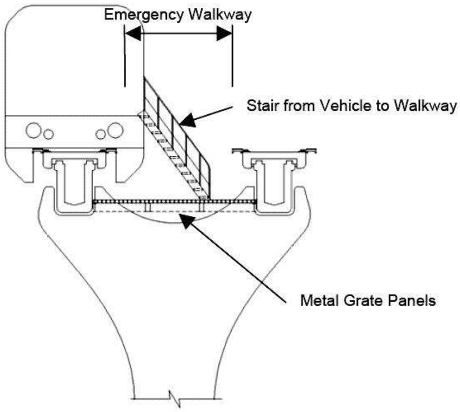

Fig. 12. Metal grate panels

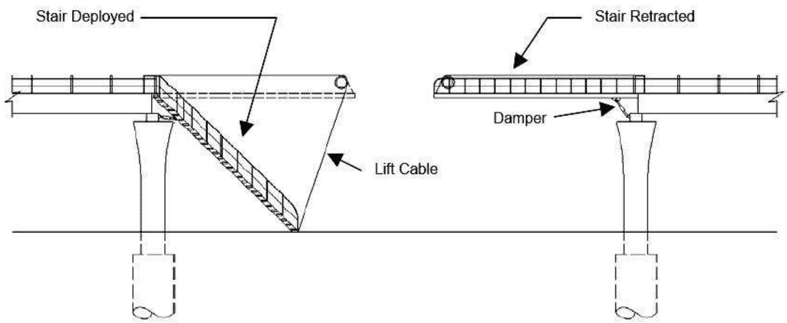

Fig. 13. Stairs from emergency walkway to ground

Fig. 14. Emergency door and ladder

6.3 Operation control system (OCS)

The OCS comprises all technical facilities for planning, monitoring and safeguarding of vehicle operation which means a combination of automatic vehicle operation (ATO) and automatic vehicle protection (ATP) functions like e.g. providing a safe vehicle travel path in order to avoid collisions and the monitoring of vehicle travel speed range in order to assure stopping only at predefined stopping points. The OCS consists of central, wayside and mobile components with interactions to other sub-systems respectively operational and maintenance staff (Fig. 15).

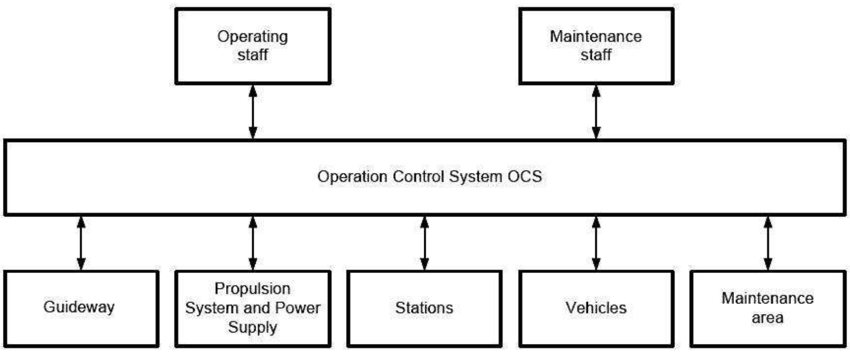

Fig. 15. Structure of the OCS

The system is involved in the assessment of the sub-systems Operation Control System, maglev vehicle and guideway switches are responsible for the overall system safety assessment for the safety concept, rules and regulations for operation and maintenance during commissioning and commercial operation and effectiveness of staff training. The Guideline Mü8004 (the traditional German signaling guide-lines for main lines) distinguishes safety relevant (vital) and not safety relevant (non-vital) requirements (Sawilla & Otto, 2006).

Operation control system (OCS) is the part of an overall maglev system that integrates all subsystems like operation control center, guideway elements, stations, maintenance areas, propulsion and power supply, and vehicles. An OCS contains all components and functions to control and monitor the safe maglev operation. OCS allows control of the vehicle movements and guideway elements both manually and automatically. On the base level, OCS provides all the safety functions generally known in railway signaling, e.g. vehicle locating, guideway switch control, route protection (interlocking), and automatic vehicle control including speed profile monitoring. There are some crucial differences between OCS and most existing railway signaling systems. All vehicle control and vehicle detection (vehicle locating) functions are purely communication-based, using a highly available radio system. Only the safe vehicle brake is used by OCS for emergency braking if the service brake is failed. Emergency systems are mechanical. They act simultaneously if there is an emergency. Each system is controlled by separate component of on-board computer. Emergency systems are independent on each bogie. Each component in the system checks the others. Each component controls at least one of the braking systems. The interior has been designed to concentrate upon the urban commuters' convenience and safety. Whole interior fittings such as panel, floor and seats are made of non-combustible material comply with international fire and safety standards, (Fig. 16) (FTA, 2005a). There are also some innovative safety functions like minimum speed profile monitoring which guarantees the availability of designated stopping points in the event of power shut-offs, transmission failures or hardware faults.

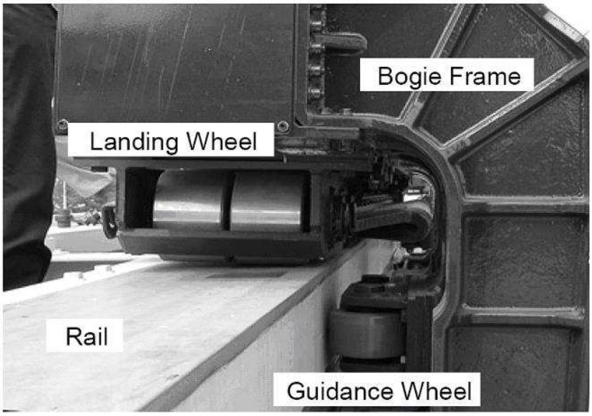

Fig. 16. Emergency landing and guidance wheel

The OCS functions comprise of:

- - Ensure safe movement of vehicles
- - Ensure safe route
- - Ensure safe separation of vehicles
- - Ensure safe speed
- - Authorize vehicle movement
- - Ensure detection and management of emergency situations
- - Handle emergency situation

(Kron Hans, 2006a).

The operation control system (OCS) monitors and controls the various subsystems, integrating them to form a safe, automated overall system. (Kron Hans, 2006b).

6.4 Safety life-cycle

The risk analysis pertaining to the safety concept for maglev vehicles, which is a key document, is an important criterion in the implementation process for the entire project in accordance with the DIN EN 50 126 life-cycle model, (Fig. 17). The European railway life-cycle standard DIN EN 50126 defines a process, based on the system life-cycle including RAMS management. It is applicable to modifications of existing systems in operation prior to the creation of the standard, although it is not generally applicable to other aspects of the existing system (Steiner & Steinert, 2006).

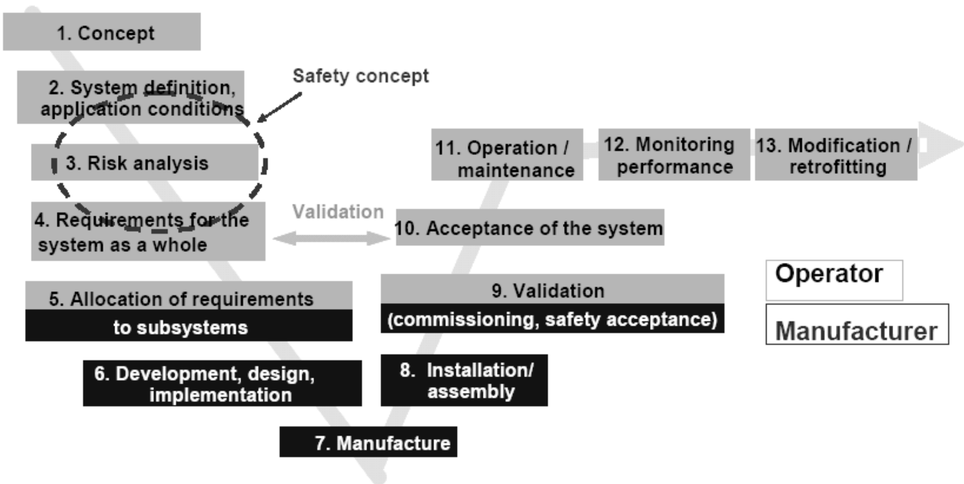

Fig. 17. Life-cycle model

An OCS may only be approved by the safety authority and accepted by the maglev transport authority if both the generic subsystem and the corresponding application data have successfully passed the safety life-cycle, including (Kron Hans, 2006b):

1. Verification - to determine by analysis and test that the output of each life-cycle phase meets the requirements of the previous phase
2. Validation - to demonstrate by analysis and test that the system meets in all respects its specified requirements
3. Safety assessment

7. Technical comparison of maglev and HSR

The need for rapid transit systems has become vital in both urban and intercity travels. There are two technologies for these systems, high-speed rail (HSR) and magnetic levitation (maglev). They are dramatically different in lots of terms. This section focuses only on the technical comparison of these technologies. For a comprehensive comparison, many criterions are included. In fact, this part surveys technical advantages of the maglev systems over the HSR systems.

Mobility and transportation infrastructure is a primary need for the population. They guarantee a high grade of freedom and quality for the citizens, for their work and leisure time. Infrastructure is an important location factor in the regional and global sense. It strongly influences the development of the society and the growth of the national economies. The mobility of individuals is impossible without an equivalent volume of traffic and transportation infrastructure. Against the background of increasing energy requirement, limited fossil resources and ever-growing CO2-loads, the road traffic may not be the adequate answer for the challenges of the future developments. It is necessary to establish integrated and sustainable traffic systems for the effectively and environmentally acceptable handling of traffic (Naumann et al., 2006). Cities' developments lead to a considerable increase of the road, a capacity overloads of road traffic network, and an increase of stresses for people and environment. The transport policy must be faced up to this challenge and take appropriate measures in time. A major vision is the development and implementation of rapid transit systems, which can relocate certain parts of road and air traffic to these systems and to enhance growth of congested urban areas and coalescence of the area (Schach & Naumann, 2007).

The congestion in transportation modes associated with increased travel has caused many problems. These problems include the public concern, among which are prolonging travel time, growing accident rates, worsening environmental pollution, and accelerating energy consumption. On the contrary, high-speed ground transportation, characterized by high speed, operating reliability, passenger ride comfort, and excellent safety record, is considered one of the most promising solutions to alleviate the congestion. There are two distinguished technologies, HSR and maglev. Both provide higher operating speed. However, they have dramatically different technical specifications. Various organizations in the world are facing difficult decisions, when choosing or settling on a specific technology, in a particular corridor. Due to the complexities of HSR and maglev technology, it is not an easy task to select the most efficient technology in any given corridor.

A new rapid transit system influences the society, the industry and the ecology in various manners. A HSR or maglev system must prove its advantages. Therefore, extensive and detailed studies must be carried out. It must be examined in an intense planning process, with feasibility studies. The criterions for the decision must be evaluated in a multi-criteria procedure. This process delivers a master plan for new construction of the transportation network. The plan for the research and development of a rapid transit technology should be made at the national level. The study focuses only on the technical comparison of these technologies. For a comprehensive comparison, a lot of criterions are included. It leads to a wider consideration and the development of the technical comparison. It comprehensively compares the characteristics of HSR and maglev in detail in different aspects. These aspects include geometrical requirements, speed, acceleration, RAMS, environmental impacts, energy consumption, noise emission, vibration level, land use, loading, etc. The obtained results clearly indicate that the maglev generally possesses better technical advantages over HSR.

Rapid transit system is a definition that covers both HSR and maglev. It is defined as an intercity passenger transit system that is time-competitive with air and/or auto on a door-to-door basis. This is a market-based, not a speed-based, definition: it recognizes that the opportunities and requirements for high-speed transportation differ markedly among different pairs of cities (Liu & Deng, 2004). The fundamental reason for considering the implementation of rapid transit systems is higher speed, which can easily equate to shorter travel time. Therefore, there is a need to look at the technical specifications of each technology. This examines the potential improvement of each technology in terms of speed, travel time and other advantages.

HSR trains represent wheel-on-rail passenger systems. These trains currently operate at maximum speeds of about 350 km/h in China, and have been tested at 574 km/h in France. Examples of HSR trains include the French Train à Grand Vitesse (TGV), the Japanese Shinkansen, the German Intercity Express (ICE), the Spanish AVE, etc. Maglev is an innovative transportation technology. It is the first fundamental innovation in the field of railway transportation technology.

HSR and maglev systems are each developed for specific purposes. Selection of the appropriate technology will depend primarily on acceptable funding levels, transportation objectives, and implementation schedule (Najafi & Nassar, 1996). Rapid transit systems must fulfill the major elements of the transport politics. The main aims consist in the increase of speed in the transportation corridors, flexibility, environmental acceptance, ride comfort, stresses (noise, pollutions, and vibrancies), etc. The two existing rapid transit systems must be evaluated and compared against the background of these requirements and the traffic demands.

HSR and maglev are guided ground transportation modes with very large capacity, and both use electric power from the utility grid for propulsion. They also exhibit some fundamental differences that distinguish them as very separable transportation modes. Maglev systems offer the unique combination of technical attributes. These include light weight vehicles, centralized and fully automated control of propulsion systems, non-reliance on adhesion for vehicle acceleration and braking forces, and the ability to operate with consists of as little as single cars. These cars carry fifty to one hundred passengers without the need for highly-skilled operators. The ability to use single or double-car allows even relatively small markets to be given high frequency, reliable service. This together with frequent, highly reliable service, are required to attract new ridership and divert passengers away from their cars. The maglev technology attracts a significantly greater ridership and provides more benefits than HSR systems.

Fig. 18 shows a classification to compare the different parameters for the rapid transit systems in this research. The paper focuses only on the technical comparison of the maglev and HSR systems. For a comprehensive comparison, a lot of criterions are included. It leads to a wider consideration and the development of the technical comparison. The purpose of this research is not to recommend one technology over the other. Actually, both technologies are highly advanced and have some advantages. However, this research surveys technical advantages of the high-speed maglev systems over the HSR systems (Yaghoubi, 2011; Yaghoubi et al., 2011).

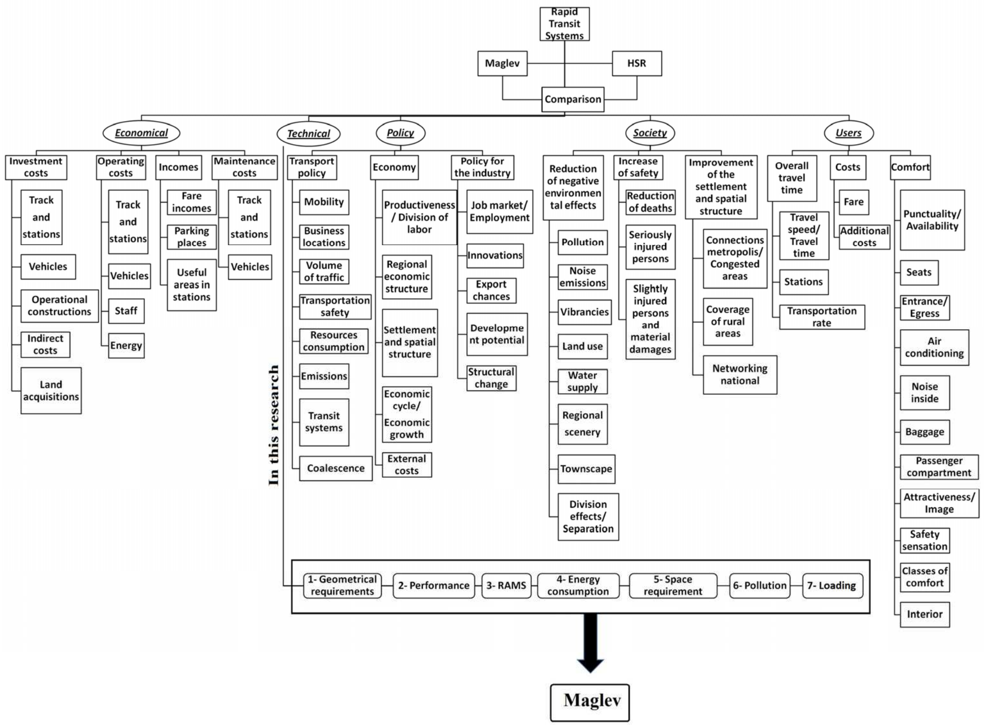

Fig. 18. Classification to compare different parameters

In general, there are many good reasons to turn to magnetically levitated trains. By lower levels of consuming energy, pollution, less noise emission and vibration level, maglev vehicles cause fewer disturbances to the nature and have increased compatibility with environmental issues. Possibility of traveling on elevated guideways means less land occupation. In addition, maglev guideway has lower dead loading. These vehicles can travel at steeper gradients and are capable of traveling at higher speeds with increased accelerations and higher braking, more effective use of regenerative as opposed to dynamic electrical braking, and lower staff and maintenance costs. Maglev vehicles have lower static and dynamic loading, higher passenger capacity and increased passenger comfort and convenience. Such vehicles can travel along routes with lower curve radiuses. They are reliable, reasonably safe, and convenient. Other benefits of maglev systems include travel time, health, flexibility, frequency, operational and schedule reliability (weather and equipment delays), accessibility, safety and security, system availability (origin and destination). Amongst the most important aspects of using maglev vehicles is the possibility of traveling at 10% grades while for high-speed trains such as German ICE this grade angle reduces to 4%. This important aspect considerably reduces the total length of the routes for maglev vehicles. As a further bonus, the cost of constructing and establishing maglev routes at grades and hilly areas considerably reduces. Maglev is obviously the most attractive and powerful transportation system. On the other hand, it is particularly suitable for long-distance transportation of passengers. Maglev is very competitive with air transportation at long distances and against passenger cars at distances starting of 100 kilometers. In contrast to maglev, HSR is only conditionally able to compete with passenger road and air traffic at shorter distances between approx. 150 and 350 kilometers (Naumann et al., 2006).

7.1 Geometrical requirements

Although the guideway has the different procedure with the manufacturing and examination, its geometrical requirements and criteria can be compared with railway tracks. The engineering rules of guideway geometry specification define the requests at the function planes of the guideway and their permissible deviations from the nominal values. These tolerances are valid for a guideway girder, finished equipping and under load of dead weight of the girder. The geometrical examination occurs to the outfit of the girders with the functional components in the manufacturing plant. Based on the defined space curve geometry, the deviations to that can be represented graphically. A comparable criterion of the wheel-on-rail system is the internal, shortwave geometry. This is with 2 mm related to 5 m length indicated in each case for layout (y-direction) and height (z-direction). Standardized onto a consideration length of 1 meter the comparative value turns out 1.5 mm/m at the maglev and 0.4 mm/m at the wheel-on-rail-system. It results from that this tolerance request is significantly higher at the wheel-on-rail system. The tolerance requests at the geometry are approximately identical with both systems. The comparison of the geometrical requests between the maglev and wheel-on-rail shows that similar tolerance requests are made. During the change of the inclination at the wheel-on-rail, track system is approximately 4-times higher as the maglev guideway (Suding & Jeschull, 2006).

7.2 Performance

Based on little wear and tear, the maintenance of the maglev system is less than that of the HSR systems. Due to high operating speed and acceleration, abilities and the low maintenance expenses' maglev can reach very high operation performances (Köncke, 2002). Maglev generally has an advantage over HSR in terms of travel speed. The operating speed of maglev is about 45% higher than that of the HSR trains (Liu & Deng, 2004). The limited speed of HSR is always the main concern of railway professionals. Resistance increases as the speed increases, which limits the increase of speed of HSR. On the contrary, high-speed potential is an inherent characteristic of the maglev technology.

If the speed of each mode plays a key role in the travel time comparison, acceleration and deceleration rate is an even more important factor in terms of safety spacing and average travel speed over certain distances. The maglev vehicle accelerates quickly to higher speeds. Acceleration and braking capabilities of the maglev system result in minimal loss of time for station stops. The vehicles reach high operating speeds in a quarter of the time and less than one quarter of the distance of HSR systems (AMG, 2002).

A maglev vehicle with acceleration/deceleration rate of 1 m/s^2 can obtain the maximum speed in much less time and space than HSR trains. For example, the distance required for the maglev vehicle to accelerate to 300 km/h from a standing start is just about 4-5 kilometers, while HSR trains require about 20-23 kilometers and over twice the time to reach the same speed. Therefore, this advantage of the maglev system results in much less loss of the time for the station stops. The German TR08 maglev vehicle takes 265 s and 19.3 km for the acceleration to achieve the speed of 500 km/h, which are less and shorter than the corresponding values 370 s and 20.9 km for ICE03 train to achieve 300 km/h. The deceleration time and distance via maglev are both shorter so it can maintain ideal speed much longer. The eventual travel time via HSR doubles that of maglev even though the analysis only presented about 50% difference (Liu & Deng, 2004; Witt & Herzberg, 2004; Baohua et al., 2008).

The maglev vehicles can easily overcome uphill gradients and slopes with inclinations up to 10 % comparing to a maximum 3.5 % - 4 % for the HSR trains. In general, the maglev vehicle can climb grades from 2.5 to 8 times steeper than HSR trains with no loss of speed. Embankments and incisions are necessary for the compensation of the small ability of climbing and the constructive design of the guideway. This can lead to a considerable land use. The maglev vehicles can negotiate 50-percent tighter curves (horizontal and vertical) at the same speeds as HSR trains. They can travel through a curve of the same radius at much higher speeds than HSR trains. For example, the maglev vehicle can cant up to 16°. The minimum curve radius of the maglev guideway under the speed of 300 km/h is also 1590–2360 m, which is smaller than 3350 m of HSR tracks (AMG, 2002; Liu & Deng, 2004; Dai, 2005; Jehle et al., 2006; Stephan & Fritz, 2006; Baohua et al., 2008).

Resulting from the greater propulsion performance, the maglev systems offer not only a higher travel speed but also a higher acceleration and deceleration level. The maglev accelerates very well and almost constantly with 0.9 m/s^2. Its maximum speed of 450 km/h is reached within 3 min. The ICE train requires nearly 5 min until it reaches its maximum speed of 300 km/h. Moreover, the maglev vehicle may run approaches to the stop stations in urban surrounding with a speed of 250 km/h due to its low noise emissions and vibrations. The pure running time difference of both systems regarding a line length of approximately 300 km from Berlin to Prague amounts of 29 minutes (50 % more) (Stephan & Fritz, 2006).

Table 12 shows the results of comparison between a maglev train and a HSR train from operational viewpoint (Schach & Naumann, 2007; Liu & Deng, 2004; Witt & Herzberg, 2004; Köncke, 2002; Baohua et al. 2008).

7.3 Reliability, availability, maintainability and safety

An important issue in the proper operation of rapid transit systems is the reliability, availability, maintainability and safety (RAMS). RAMS is the item that needs to be considered in any new rapid transit system establishment. This item is the factor that affects the passenger's mode choice decisions and is important for project evaluation. Safety is amongst most important factors for ensuring operational of integrity high-speed trains. Maglev is one of the safest means of transportation in the world. The concept of maglev has essentially eliminated the safety risks associated with the operation of HSR systems. The use of a dedicated and separated guideway without intersections with other transportation modes such as roads and highways ensures no safety conflicts and allows uninterrupted maglev operations. The maglev technology has essentially eliminated the safety risks associated with the operation of rapid transit systems. Compared to the operating experiences of HSR, the maglev technology has a scarce record. On the other hand, the German Transrapid Test Track in Elmsland has been operating for more than 20 years and

Parameter	Unit	InterCityExpress (ICE) 3 ICE-03 the type series 403		Transrapid Shanghai Maglev TR-08 SMT the type series TR 08				
Operational maximum speed	km/h	until 300		until 450				
Sections per vehicle		8		5 (from 2 to 10 possible)				
Seats (on average)		415		446				
Length (total)		200		128.3				
Capacity		8: 850		10: 1192				
Maximum engine performance	kW	8.000		approx. 25.000				
Power Requirement at Constant Speed of	MW			Train Sections				
				2	6	10		
200	km/h			0.9	2.2	3.6		
300	km/h			2.2	5.0	7.9		
400	km/h	-		4.4	10.3	16.1		
500	km/h			8.2	18.7	-		
Net weight vehicle	ton	409		247				
Weight / Seat	kg	Approx. 930		Approx. 550				
Maximum longitudinal gradient	%	3.5		10				
Acceleration	m/s²	maximum 1,0		constant 1,5				
Acceleration	m/s²	Distance (m)	Time (s)	Distance (m)	Time (s)			
0- 100	km/h			424	31			
0- 200	km/h	4400	140	1700	61			
0- 300	km/h	20900	370	4200	97			
0- 400	km/h			9100	148			
0- 500	km/h			22700	256			
Train Configuration		Driving Trailer/ End Car	Trailer Car	End Section	Middle Section			
Train Size		2	6	2	0-8			
Section Length	m	25.68	24.78	26.99	24.77			
Section Width	m	2.95	2.95	3.70	3.70			
Section Height	m	3.84	3.84	4.16	4.16			
Payload / Section	ton	-		10.3	13.9			
Seats / Section		-		62-92	84-126			
Floor Space / Section	m	-		70	77			
Weight / Seat	kg	Approx. 920 to 1000		500 – 700	400 – 600			
Number of Sections		8		2	4	6	8	10
Seats (high density)		408 to 418		184	436	688	940	1192
Seats (low density)		-		124	292	460	628	796
Passengers	ton	-		20.6	48.4	76.2	104	131.8
Curve Radii	m							
Minimum	km/h	300		350				
200	km/h	1400		705				
250	km/h	2250		1100				
300	km/h	3200		1590				
350	km/h	-		2160				
400	km/h	-		2825				
450	km/h	-		3580				
500	km/h	-		4415				

Table 12. Comparison between two German trains of ICE-03 HSR and TR-08 maglev

close to a million passengers have ridden around the 40-kilometer closed loop. The maglev vehicle wraps around the guideway beam so it is virtually impossible to derail. Redundancies achieved through the duplication of components as well as the automated radio-controlled system ensure that operational safety will not be jeopardized. The principle of synchronized propulsion on the guideway makes collisions between vehicles virtually impossible. In general, no other obstacles can be in the way. If two or more vehicles were ever placed simultaneously in the same guideway segment, they would be forced by the motor in the guideway to travel at the same speed in the same direction. The vehicles are also designed to withstand collisions with small objects on the guideway. Energizing only the section of the guideway on which the train is traveling enhances operational safety and efficiency. The maglev vehicle is absolutely weatherproof and masters wind and adverse weather easily. Regarding the aspect of fire protection the maglev vehicle meets the highest requirements of the relevant standards. No fuels or combustible materials are on board. All used materials within the vehicles are PVC-free, highly inflammable, poor conductors of heat, burn-through-proof and heat-proof. The fire proof doors can be optionally used in order to separate the vehicle sections. The system is controlled in all the directions of the movement to ensure ride comfort throughout all the phases of the operation. The seat belts are not required, and passengers are free to move about the cabin at all speeds (AMG, 2002; Köncke, 2002; Liu & Deng, 2004; Dai, 2005).

7.4 Energy consumption and space requirement

With non-contact technology, there is no energy loss due to the wheel-guideway friction. The vehicle weight is lower due to the absence of wheels, axles and engine (low mass of approx. 0.5 t per seat). In terms of energy consumption, the maglev vehicles are better than HSR trains. The maglev consumes less energy per seat-mile than HSR trains due to the utilization of lightweight materials and improvement in the advanced technology. The energy consumption of the maglev system with its non-contact levitation and propulsion technology, highly efficient linear motor and low aerodynamic resistance is very economical when compared to other transportation modes. The high-speed maglev system consumes 20 to 30 percent less energy per passenger than the very modest railroad. With the same energy input, the performance of the maglev system is substantially higher than HSR systems (Liu & Deng, 2004; Köncke, 2002).

As consumers of energy, the transportation sectors are vulnerable to environmental and global warming concerns and the increasing volatile oil market. Reducing dependency on foreign oil is also an important criterion. The system of the external power supply over the contact rail causes higher investment and operational costs. The energy costs of the maglev vehicle despite higher design speed, is lower than that of ICE3 train (Witt & Herzberg, 2004). The maglev vehicles running at 400 km/h has lower environmental impact indicators, such as system energy consumption, waste gas discharges, site area and the like, then the ICE trains running at 300 km/h (Baohua et al., 2008). They also have low running resistance of approx. 0.2 kN per seat at 400 km/h (Köncke, 2002).

Maglev is one of the first transportation systems to be specially developed to protect the environment. The system can be co-located with existing transportation corridors and needs a minimum amount of land for the support of the guideway beams. Use of the elevated guideway minimizes the disturbance to the existing land, water and wildlife, while flexible alignment parameters allow the guideway to adapt to the landscape. Compared to roads or railway tracks, especially the elevated guideway does not affect wildlife movement. Even the ground-level guideway allows small animals to pass underneath due to the clearance planned under the guideway. Compared to all other land-bound transport systems, the maglev requires the least amount of the space and the land. The land area required for a ground-level double-track by either maglev or HSR systems is about similar so it is 14 m^2/m and 12 m^2/m, respectively. But for an elevated double-track guideway, approx. 2 square meter of land is needed for each meter of guideway (Schwindt, 2006). Considering the densely populated and limited land resources, an elevated structure is a preferred choice. The traffic effects on the land-use have been always considered by urban planner and transportation engineers. In the center of metropolitan areas with large economic activities, such as Mashhad, the increase of traffic volume has indirectly cost. It includes wasting time and damages such as environmental pollution.

7.5 Pollution

As maglev is electrically powered, there is no direct air pollution as with airplanes and automobiles. The maglev causes lower CO2 emissions. It is also easier and more effective to control emissions at the source of electric power generation rather than at many points of consumption. Maglev is the quietest high-speed ground transportation system available today. Due to its non-contact technology, there is neither rolling nor gearing or engine noise. The frictionless operation of the maglev vehicle reduces vibration and maintenance resulting from wear. Comparing the noise levels at different speeds, the maglev vehicle is much quieter than the HSR trains. For example, The German TR07 maglev vehicle can travel about 25 percent faster than existing HSR trains before reaching the peak noise restrictions of 80 to 90 dBa. Such an advantage in speed will yield reduced the trip times along the noise-limited routes, which is most urban areas. At the speeds up to 200 km/h, the noise level compared to other noises from the surroundings can hardly be heard. At 250 km/h, the pass-by noise level is 71 dB(A), and from 250 km/h upwards, the aerodynamic noises begin to dominate the noise level. The result is that, at the speed of 300 km/h, the system is no louder than a light rail vehicle, and at 400 km/h, the noise level can be compared to a conventional train traveling at around 300 km/h. Even when at respective high speeds, data also indicates that maglev vehicle is 5 to 7 dBa quieter than the HSR train (Liu & Deng, 2004; Dai, 2005; Schwindt, 2006). The American JetTrain HSR train is almost twice as noisy as the maglev vehicle at the similar operational speeds (AMG, 2002). The results of the noise measurements of the TR08 Maglev System may be compared with similar data, documented by the Federal Railroad Administration (FRA, 1998), for other high-speed ground transportation systems (FRA, 2002a). The noise analysis associated with the Shanghai maglev train shows that the system is quieter than high-speed railway trains for comparable distances from the track (Chen et al., 2007).

A field experiment was conducted, to investigate the possible differences in perceived annoyance of noise caused by high-speed trains, both HSR and maglev. These results were evaluated for the TGV train at speeds of 140 km/h & 300 km/h and for the maglev vehicle at speeds of 200 km/h, 300 km/h and 400 km/h. The LAeq-annoyance relationships determined for the HSR and for the maglev train did not differ significantly. This study has shown that the noise annoyance caused by different types of trains at the same average outdoor façade exposure level is not significantly different. In particular, the magnetic levitation systems are not more annoying than the HSR trains, which is in agreement with earlier research (Coensel et al., 2007).

Whatever the kind of transport system, a passing maglev vehicle always creates ground vibrations due to dynamic loading of the track. Depending on the speed, load transfer, load dispersion and the nature of the ground, these vibrations are transmitted through the ground to different degrees and may thus be felt as shocks in neighboring buildings. For especially sensitive areas, technical solutions are currently being investigated, which minimize the dynamic loads that are transferred from the vehicle to the guideway and then to the bearings in the supports and foundations (Schwindt, 2006).

TR08 vibration levels for both the concrete elevated and concrete at-grade (AG) guideways are compared with those of the TGV, the Italian Pendolino, the Swedish X2000, and the Acela at 240 km/h. The vibration levels for the TR08 traversing the at-grade guideway structures are comparable to those from HSR trains measured in Italy (Pendolino) and France (TGV), whereas the levels for the elevated structure are considerably lower for the distances measured. Vibration levels measured at 15 m for the TR08 traversing the at-grade guideway at 400 km/h are less than those previously measured at 15 m for the Acela traveling 240 km/h. These comparisons, however, are representative of data collected at various sites and are generally typical of local geological conditions. In general, ground-borne vibration levels from trains on elevated structures tend to be lower than those from at-grade operations (FRA, 2002b). The curves for European HSR trains are taken from the FRA high-speed ground transportation guidance manual (FRA, 1998), and for the Acela from measurements conducted by HMMH (FRA, 2000).

7.6 Loading

In this part of research, maglev guideways and road and railroad bridges are compared from loading and design aspects. The optimal design of all bridges, including road, railroads and maglev elevated guideways is really vital. Majority of the existing maglev guideways are elevated and completely built on the bridge. In fact, a maglev elevated guideway is one kind of bridges. Therefore, it can be compared with any bridge, including railroad and road.

According to the AREMA regulations and the UIC leaflets, the live loading models for the rail tracks, is a combination of the concentrated and distributed loads. However, the live loading models for the maglev trains, in the absence of wheels and pursuant to uniformity in the intensity of magnetic forces due to the magnets, are uniformly distributed on the guideways. The lateral magnetic force in maglev is less than the lateral force in the rail tracks. The low level of this force in maglev is due to the absence of the rails and wheels, lower weight of the vehicle and the presence of lateral restoring and equilibration magnetic force.

In general, vertical loadings (dead and live) in the spans of maglev guideways are much lower than those of the railroad bridges. The intensity of the uniform distributed load in live loading of the railroad bridges is almost four times that in maglev. One reason for this difference is the lower weight of the maglev vehicle due to the absence of wheels, axles and transmission parts plus the overall short length of the vehicle. The amount of the earthquake lateral force on the maglev guideway is less than one third of its value for the road bridge.

The loading of the guideway is almost equal to the loading of each one of the four girders of the railroad bridge. In other words, taking into account the fact that the bridge consists of four girders, comparison of the results indicates that the load on the railroad bridge deck is four times greater than the load on the maglev guideway. This means that the guideway by itself can play the role of each one of the girders of the railroad bridge (Yaghoubi & Ziari, 2011; Yaghoubi & Rezvani, 2011).

8. Conclusion

Rapid increase in traffic volume in transport systems plus the need for improving passenger comfort have highlighted the subject of developing new transport systems. The recent required increases in the traffic volume in transport systems, as well as a need for the improvement of passengers' comfort, and required reductions in track life cycle costs, have caused the subject of the development of a new transportation system. One of the important systems which have attracted industries is maglev transport system. In this regard, maglev transport system turns out to be a proper choice for transportation industries around the world. Maglev systems have been recently developed in response to the need for rapid transit systems. The maglev system comes off clearly better and surpasses the HSR systems in almost most fields. These include the pollution, noise emission, vibration level, environmental issues, land occupations, loading, speed, acceleration and deceleration, braking, maintenance costs, passenger comfort, safety, travel time, etc. With the maglev guideway it is also possible to reach to the minimal radiuses for the horizontal and vertical curves. A maglev vehicle can as well travel at the steeper gradients compared with the HSR systems. This considerably reduces the total length of track for the maglev routes compared to the HSR systems. The possibility of traveling with the higher grade angles also reduces the number of tunnels that are required to travel through the mountainous areas. This can also shorten the total length for the maglev route. Therefore, construction of the maglev routes in the hilly areas, in addition to many other advantageous of these systems, can be considered as an attractive choice for the transportation industries. The lower energy consumption of the maglev vehicles in comparison with the HSR systems is also among major characteristics of the magnetically levitated trains. This can be easily associated with the absence of the wheels and the resulting situation of no physical contact between the maglev vehicle and its guideway. Therefore, the energy loss due to the unwanted friction is out of the equations. Furthermore, the vehicle weight is lower due to the absence of wheels, axles and engine. On the other hand, reduction in the travel time considerably reduces the energy consumption. The limited energy resources that are currently available to the nation have highlighted the fact that every individual has to be the energy conscious. The government had to take steps, and it started by setting the preventative rules and the tightening access to the cheap energy resources. Clearly, the widespread application of the magnetically levitated trains for the public transport, in short and long distances, can provide the nation with huge saving in the energy consumption. This is not a fact that can be easily ignored nor can it be bypassed.

Effective parameters in the design of guideways including dead and live loads, dynamic amplification factor and deflection, and structural analysis and design criteria were investigated. According to AREMA regulations and UIC leaflets, live loading models for loading of rails, is a combination of concentrated and distributed loads. However, live loading models for maglev trains, in the absence of wheels and as a result of uniformity in the intensity of lifting magnetic forces due to support magnets, are uniformly distributed on the guideways. The guideway loading is modeled as dynamic and uniformly distributed magnetic forces to account for the dynamic coupling between the vehicle and the guideway. In general, vertical loadings (dead and live) in the spans of maglev are much lower than those of the railroad bridges. The railroad bridge dead load is four times larger than the maglev guideway dead load, and the intensity of the uniformly distributed live load on the railroad bridge is almost four times that of the maglev guideway. Moreover, loading of guideway is four times that in the railroad bridge. One reason for this difference is the lower weight of the maglev vehicle due to the absence of wheels, axles and transmission parts plus the overall short length of the vehicle. The lateral force on the maglev guideway is also much lower than that on the railroad bridge. Also, it is predicted that on the straight routes as a result of negligible lateral magnetic force, there is no considerable amount of torsion created in the cross-section. Therefore, if the beam cross-section and the vertical loading are symmetrical, special design of guideway cross-sections to overcome torsion, is not necessary. Moreover, there usually is no need for the design of deck-shaped cross-sections to care for tension lateral magnetic forces and for the moments due to vertical magnetic forces. Compared to the road and railway bridges, the amount of lateral earthquake force on maglev guideway is lower. Maglev guideways have high resistance against earthquake forces. Maglev vehicles are lighter compared to conventional railway vehicles. These lighter vehicles cause less centrifugal force. The absence of wheels and wheel/rail contact, lighter vehicles and presence of compensating magnetic forces opposing any lateral deviation are the main reasons behind the lower centrifugal forces. A distributed-load vehicle model is better than a concentrated-load model. Multicar vehicles have less car-body acceleration than does a single-car vehicle, because of intercar constraints. This indicates that the multicar vehicle would provide better ride comfort. Weight of required longitudinal bars of guideway is also one-fourth that in the railroad bridge. Deflections due to the vertical loads (dead and live) are also lower in guideways than in rail tracks. Torsion reduction, deflection reduction due to vertical loads, reduction in the costs of construction and operation, increase in resistance and technical justification, possibility of motion in higher speeds are among main reasons to utilize beams with a U-shaped cross-sections and structural continuity in the guideways. Therefore, as noticeable improvements and developments are made in structural optimization of these cross-sections, they could be considered as a good choice among other sections and could be used with a relatively high safety factor. Also, it is shown that the lower loads on the maglev guideway lead to lower bending moments and sheer forces in comparison with the railroad bridge. This indicates that the maglev support structure requires less mechanical strength than the railroad bridge support structure for the same loading pattern. A dynamic simulation for maglev vehicle/guideway interaction is essential to optimize the vehicle design and reduce the cost.

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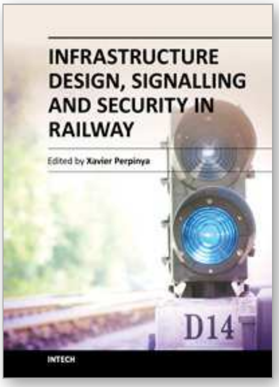

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Railway transportation has become one of the main technological advances of our society. Since the first railway used to carry coal from a mine in Shropshire (England, 1600), a lot of efforts have been made to improve this transportation concept. One of its milestones was the invention and development of the steam locomotive, but commercial rail travels became practical two hundred years later. From these first attempts, railway infrastructures, signalling and security have evolved and become more complex than those performed in its earlier stages. This book will provide readers a comprehensive technical guide, covering these topics and presenting a brief overview of selected railway systems in the world. The objective of the book is to serve as a valuable reference for students, educators, scientists, faculty members, researchers, and engineers.

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