Developing Course Lecture Notes on High-Speed Rail

Submitted to

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July 15, 2017

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High Speed Rail in the World

Definition

- High-speed rail is a type of rail transport that operates significantly **faster** than traditional rail traffic, using an **integrated** system of specialized rolling stock and dedicated tracks.
- http://en.wikipedia.org/wiki/High-speed_rail

Countries having HSR

- Austria, Belgium, Britain, China (PRC), France, Germany, Italy, Japan, Poland, Portugal, Russia, South Korea, Spain, Sweden, Taiwan (ROC), Turkey, the United States and Uzbekistan.

Early research

- First experiments
  - On 23 October 1903, the S&H-equipped railcar achieved a speed of 206.7 km/h (128.4 mph) and
  - On 27 October the AEG-equipped railcar achieved 210.2 km/h (130.6 mph)
- Early German high-speed network
  - regular top speed of 160 km/h (99 mph)
  - All high-speed service stopped in August 1939 shortly before the outbreak of World War II

Early research (cont.)

- The American Streamliners
  - Burlington Railroad's set an average speed at 124 km/h (77 mph) with peaks at 185 km/h (115 mph)
- The Italian electric
  - reached 160 km/h (99 mph) in commercial service, and achieved a world mean speed record of 203 km/h (126 mph) near Milan in 1938.
- Great Britain
  - **steam locomotive** Mallard achieved the official world speed record for steam locomotives at 125.88 mph

Early research (cont.)

- Spain
  - Talgo system, streamlined articulated train
- The first very-high-speed records - France
  - In 1956, broke previous speed records, reaching respectively 320 km/h (199 mph) and 331 km/h (206 mph), again on standard track
- Breakthrough: The Shinkansen
  - The first narrow-gauge Japanese high-speed service, 1957
  - The first Shinkansen trains, 1964, 210 km/h (130 mph)
  - Addressed diverse issues such as tunnel boom noise, vibration, aerodynamic drag, lines with lower patronage ("Mini shinkansen"), earthquake and typhoon safety, braking distance, problems due to snow, and energy consumption

Early research (cont.)

- Revival in Europe and North America
  - In France, in May 1967, a regular service at 200 km/h (124 mph)
  - American Metroliner trains achieve 200 km/h, High Speed Ground Transportation Act of 1965
  - The HST: a diesel high-speed train at 200 km/h, British, 1976
  - In 1977, Germany finally introduced a new service at 200 km/h (124 mph)
- The French TGV
  - The TGV: the first service above 250 km/h, 1981

Early research (cont.)

- In 1991 Germany was the second country in Europe to inaugurate a high-speed rail service
- In 1992, the Madrid–Seville high-speed rail line opened in Spain
- In 2000 "Acela Express“ with a maximum speed of 241 km/h (150 mph) being reached on a small section of its route through Rhode Island and Massachusetts.

Early research (cont.)

- In South Korea, Korea Train Express (KTX) services were launched on April 1, 2004
- First China high-speed rail line, the Qinhuangdao–Shenyang Passenger Railway, was built in 1999 and opened to commercial operation in 2003
- Taiwan High Speed Rail's first and only HSR line opened for service on January 5 2007

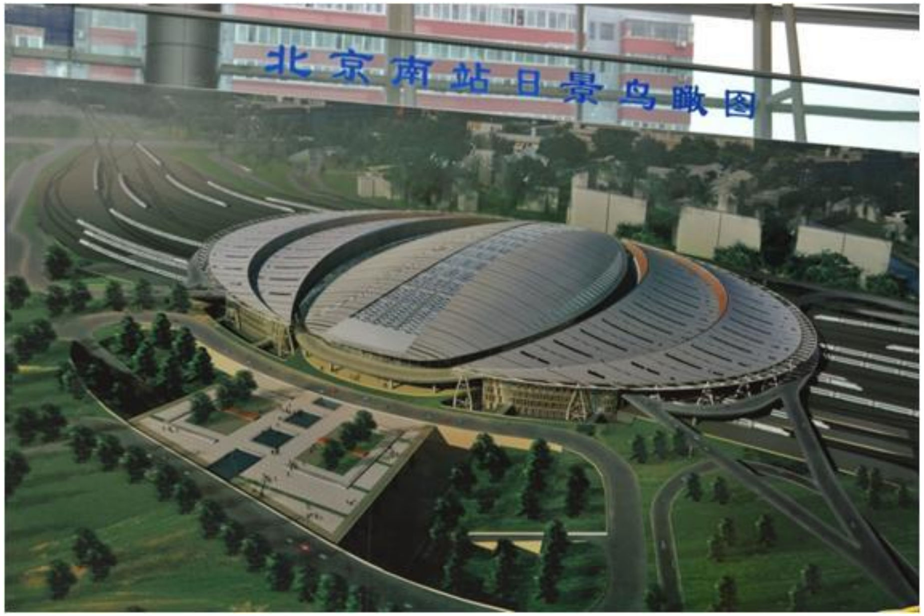
Skinkansen (Bullet Train) in Japan

Intercity Express (ICE) - Germany

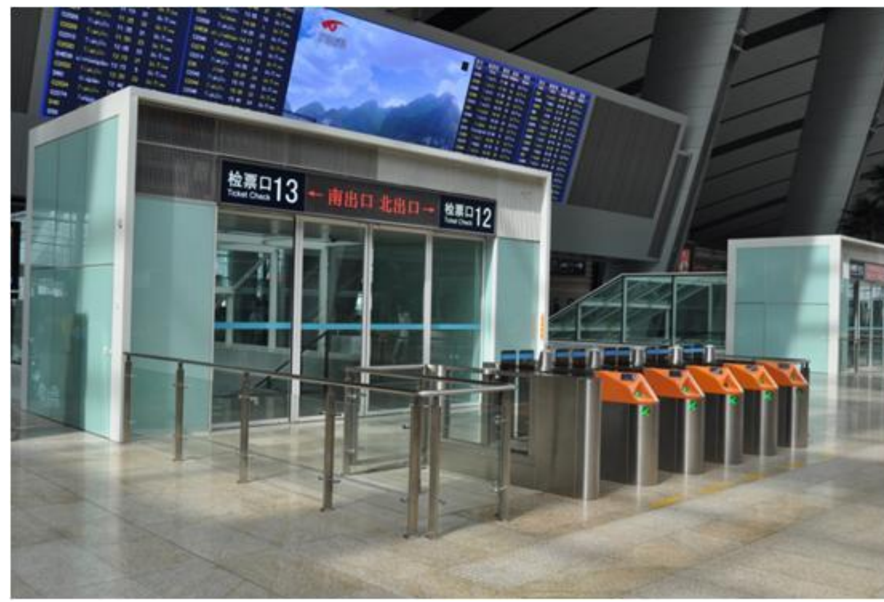
British Rail High Speed Trains

French TGV

574 km/hr
(357mph) test


北京南站日景鸟瞰图

北京南站
BEIJING SOUTH RAILWAY STATION


检票口13
Ticket Check
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Ticket Check


谐 号


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速度329km/h


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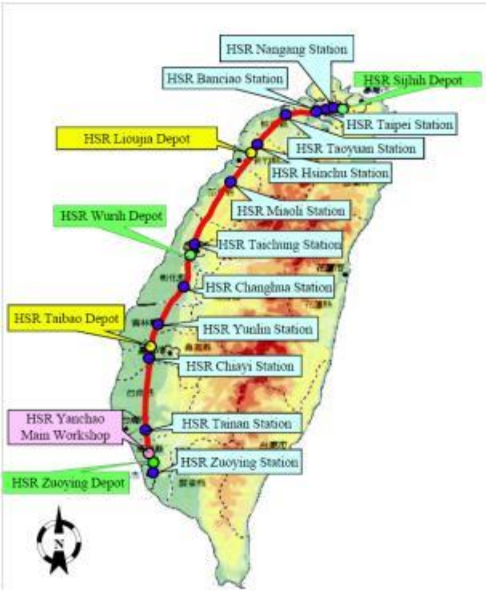
CRH

Taiwan High-Speed Rail



- The total length of the High Speed Rail is 345 km (214 mi.) from Taipei to Kaohsiung and passes through 14 cities and 77 towns.
- Stations to be constructed under the initial phase of the Project:

  Taipei, Banciao, Taoyuan, Hsinchu, Taichung, Chaiyi, Tainan, Zuoying (for Kaohsiung)
- Stations planned for later phases of the project: Miaoli, Changhua, Yunlin, Nangang
- Main Workshop: Yanchao (near Kaohsiung)
- Stabling Yard : Sijhih, Wurih, Zuoying
- Infrastructure Maintenance Bases:

  Sijhih, Lioujia, Wurih, Taibao, Zuoying
- Maintenance Center: Zuoying


HITACHI
Inspire the Next
3D智慧節能
風熨斗 ビッグドラム
滾筒式洗脫烘
智慧新滾筒 節能超效率


車上服務資訊
Information
高雄・左營 方向
板橋・台北 方向

Hsinchu, Taiwan

Photo courtesy Dr. T.C. Kao

Tainan, Taiwan

Photo courtesy Dr. T.C. Kao

Photo courtesy Dr. T.C. Kao

Photo courtesy Dr. T.C. Kao

Comparison with other modes of transport

- Optimal distance: about 150 – 900 km or 93 – 559 m
- Energy efficiency, In Japan and France, with very extensive high-speed rail networks, a large proportion of electricity comes from **nuclear power**
- High-speed rail can accommodate more passengers at far higher speeds than automobiles
- Although air transit moves at higher speeds, its total time to destination can be increased by check-in, baggage handling, security and boarding
- High-speed rail is one of the safest modes of transportation

High Speed Rail in the U.S.

Definitions in American context

- High-Speed Rail – Express
- High-Speed Rail – Regional
- Emerging High-Speed Rail
- Conventional Rail

History

- Faster inter-urbans (1920 - 1941) and Post-war period (1945-1960)
- First attempts at high-speed rail 1960-1992
  - High Speed Ground Transportation Act of 1965
    - Create regular Metroliner service between New York City and Washington, D.C.
  - The Passenger Railroad Rebuilding Act of 1980
  - Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991
- Acela Express and renewed interest in high-speed rail 1993-2008
  - No dedicated high-speed rail line, although it reaches a maximum speed of 149 mph on small sections of its route

History (cont.)

- Recent plans: 2008–2013
  - The California High-Speed Rail network, which was authorized by voters with Proposition 1A in 2008
  - In 2012, a dedicated high-speed rail line between Washington D.C. and Boston is proposed, with estimated $151 billion and take more than 25 years to design and build the line. The proposed rail line would allow for top speeds of 220 mph (354 km/h)

Current state and regional efforts

- The Northeast
  - Northeast Corridor: Next Generation High-Speed Rail, Northeast Maglev proposal, New Jersey-New York City upgrades, New York State, Pennsylvania
- West Coast
  - California, Pacific Northwest, Colorado/New Mexico
- Mid-Atlantic and the South
  - Florida, Southeast, Texas
- Midwest
  - Illinois and the Midwest, Ohio
- The Southwest

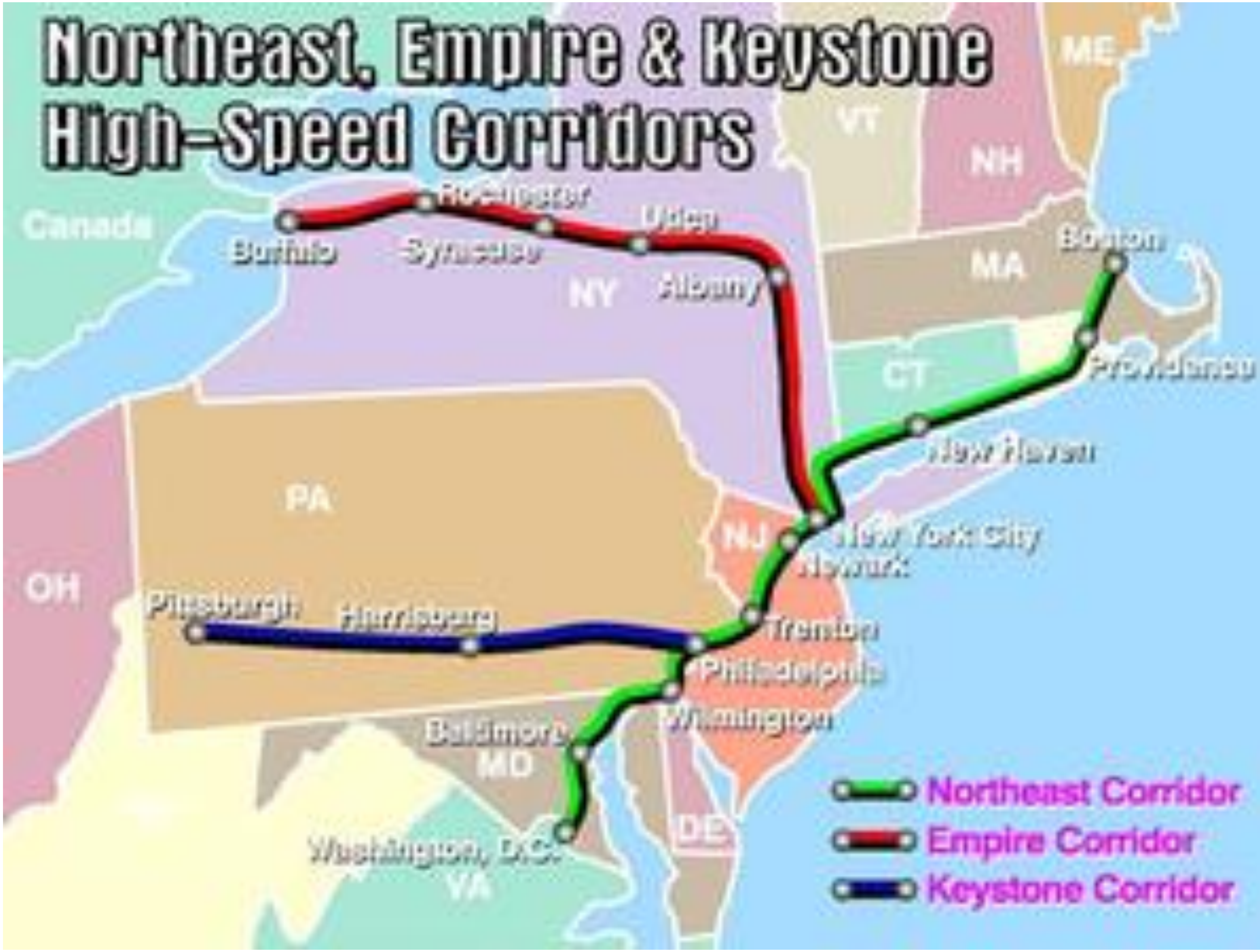
The Northeast

- Northeast Corridor: Next Generation High-Speed Rail

- http://www.northeastbizalliance.org/2011/10/amtraks-vision-for-high-speed-rail.html

Northeast (cont.)

- Northeast Maglev proposal
  - from Washington DC to New York City with the travel time of 60 minutes
- New Jersey - New York City upgrades
- New York State
- Pennsylvania


Northeast, Empire & Keystone
High-Speed Corridors
Canada
Buffalo
Rochester
Syracuse
Utica
Albany
NY
VT
NH
ME
MA
Boston
CT
Providence
New Haven
PA
NJ
New York City
Newark
OH
Pittsburgh
Harrisburg
Trenton
Philadelphia
Wilmington
Baltimore
MD
DE
Washington, D.C.
VA
Northeast Corridor
Empire Corridor
Keystone Corridor

West Coast

- California
- Pacific Northwest
- Colorado/New Mexico

- California Proposition 1A

- The Cascadia high-speed rail
- Halted due to safety and other freight service concerns voiced by UPRR

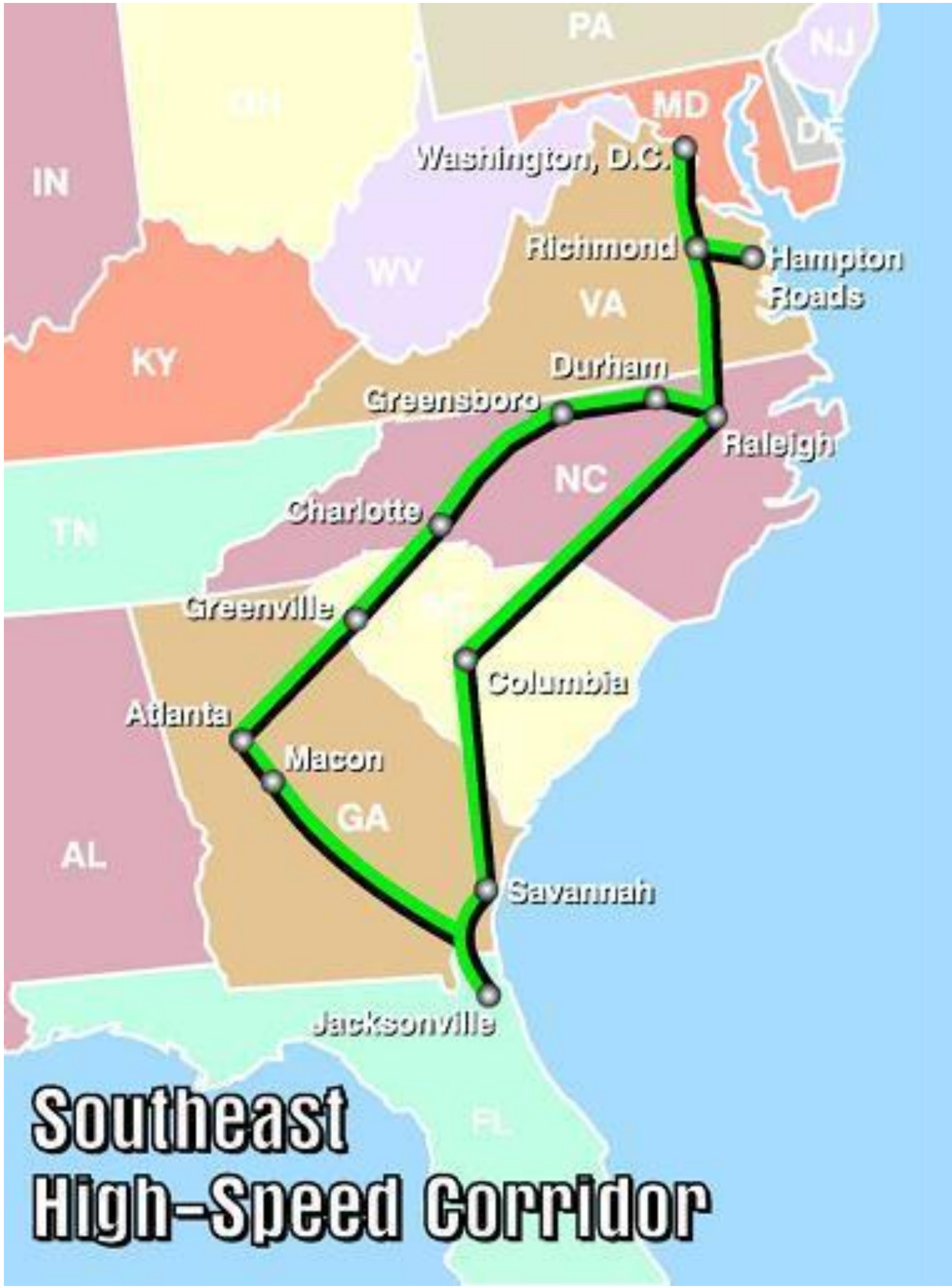
Colorado/New Mexico

- A high-speed rail corridor linking Denver, Albuquerque, and El Paso
- Request up to $5 million in federal funding for a feasibility study

Mid-Atlantic and the South

- All Aboard Florida

- Southeast


PA
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NC
SC
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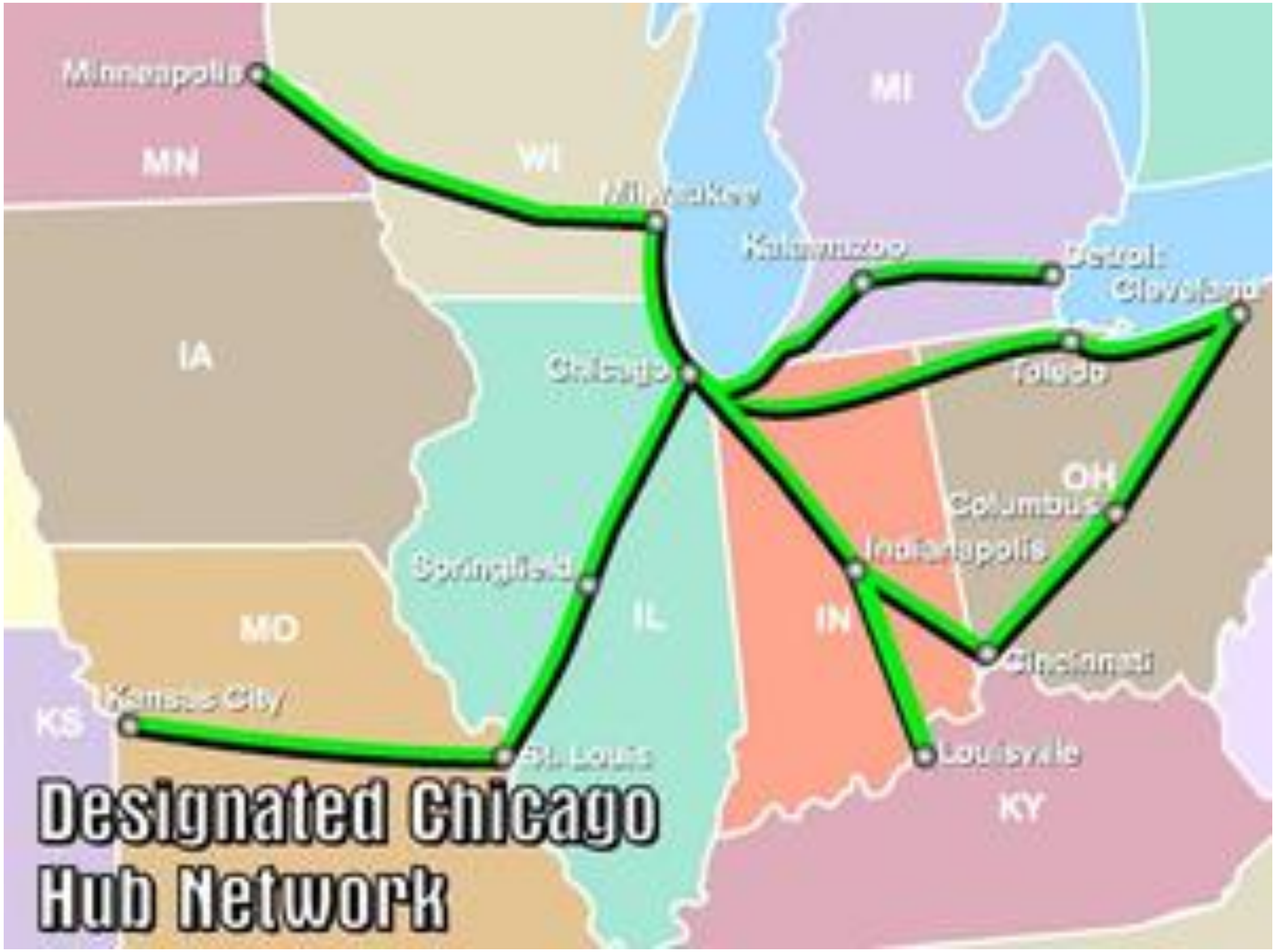
AL
FL
Washington, D.C.
Richmond
Hampton Roads
Durham
Greensboro
Raleigh
Charlotte
Greenville
Columbia
Atlanta
Macon
Savannah
Jacksonville
Southeast
High-Speed Corridor

Texas

- 1990: Texas Triangle, Texas TGV Corporation vs. German ICE
  - Opposed by Southwest Airline, McDonald, Days Inn, …
- 2002, Trans-Texas Corridor, canceled 2009
- 2002, Texas High Speed Rail and Transportation Corporation (THSRTC) formed, Joined by AA and Continental Airline, Texas T-Bone and Brazos Express corridors
- 2010: linking Oklahoma City with Dallas – Fort Worth (Federal), 2011: Dallas to Houston, 2012: Austin to Houston
- 2009, Texas Central Railway, Central Japan Railway Company, 10B

Texas

Midwest


Minneapolis
MN
WI
MI
Detroit
Cleveland
IA
Chicago
Toledo
OH
Columbus
Indianapolis
Springfield
IL
IN
MO
Cincinnati
Kansas City
KS
St. Louis
Louisville
KY
Designated Chicago Hub Network

Midwest (cont.)

- Ohio Hub

Southwest

- Desert Xpress

XpressWest


SALT LAKE CITY
LAS VEGAS
LOS ANGELES
DENVER
VICTORVILLE
PALMDALE
PHOENIX


XPRESSWEST
THE SOUTHWEST NETWORK
SWN
▪ 420 Miles
- Las Vegas
- Los Angeles
- San Diego
NEC
▪ 450 Miles
- Boston
- New York
- Washington DC
NEVADA
CALIFORNIA
Sacramento
Stockton
San Francisco
SFO
Redwood City
Modesto
San Jose
Merced
Gilroy
Fresno
Hanford
Bakersfield
San Luis Obispo
XPRESSWEST Southern California Station
Palmdale
Barstow
Victorville
San Bernardino
Las Vegas
Kingman
Needles
Santa Barbara
Oxnard
Sylmar
Burbank
Industry
ONT
Riverside
Los Angeles
Commerce
Anaheim
Irvine
Murrieta
San Clemente
Oceanside
Escondido
University City
San Diego
Station
Airport Station
California High Speed Rail
Metrolink / Amtrak
Xpresswest
N

California-Nevada Interstate Maglev Project

Federal Proposals High-Speed Rail Initiatives

11 Corridors

1. NEC
2. Southeast Corridor
3. California Corridor
4. Pacific Northwest Corridor
5. South Central Corridor
6. Gulf Coast Corridor
7. Chicago Hub Network
8. Florida Corridor
9. Keystone Corridor
10. Empire Corridor
11. Northern New England Corridor

2009 funding

Corridor	Grant received (in millions $)
Chicago Hub/Ohio	2617
California	2343
Florida	1250
Southeast	620
Pacific Northwest	598
Northern New England	160
Empire	152
Northeast	112
Keystone	27

2010 funding

Corridor	Grant received (in millions $)
California	898
Florida	800
Chicago Hub	428
Connecticut	121
Southeast	45

2011 & 2012 Proposals and Rejections of Funding

- China had built 5,000 miles (8,000 km) of dedicated high-speed rail lines in only 6 years

Geometric Design

-- Horizontal Curve

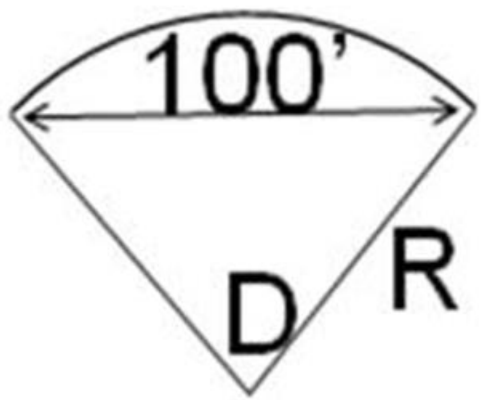
Outline

- Curvature
- Elevation
- Spiral curve

Curvature

- For conventional high speed rail train, curve of one degree or less is desirable
- The desired speed for high-speed tilt trains is one-degree-30” less

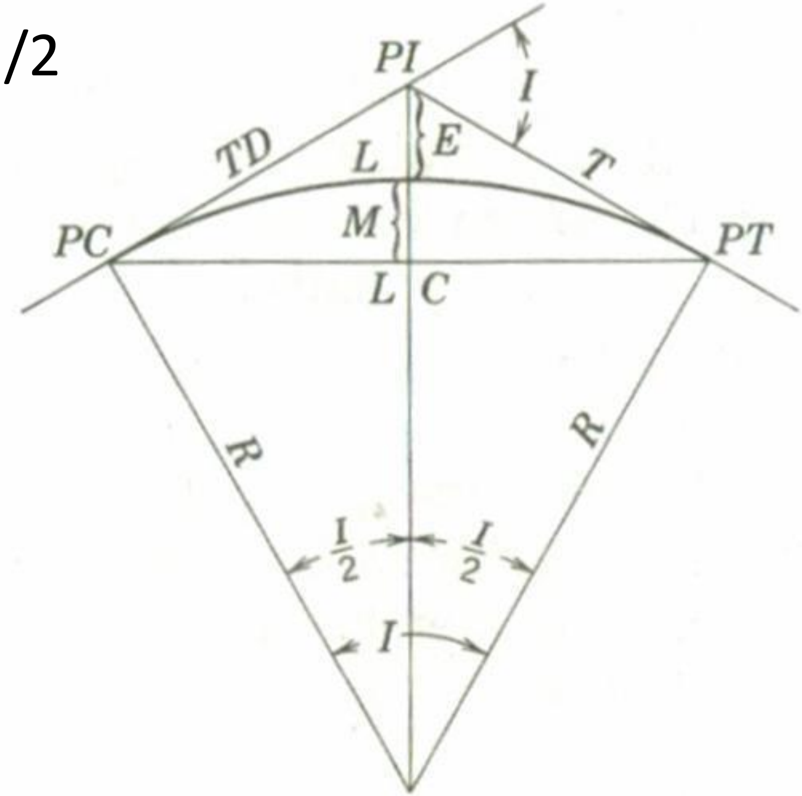
- Chord (Railroad)
  - Angle measured along the length of a section of curve subtended by a 100’ **chord**



R = 50/sin(D/2)

- 1-deg curve, R=5729.65’
- 7-deg curve, R=819.02’

- Horizontal Curves
  - Functions of Simple Curves
    - Tangent Distance = TD = R tan I/2
    - Long Chord = LC = 2R sin I/2
    - Mid-Ordinate = M = R vers I/2
    - External Distance = E = R exsec I/2

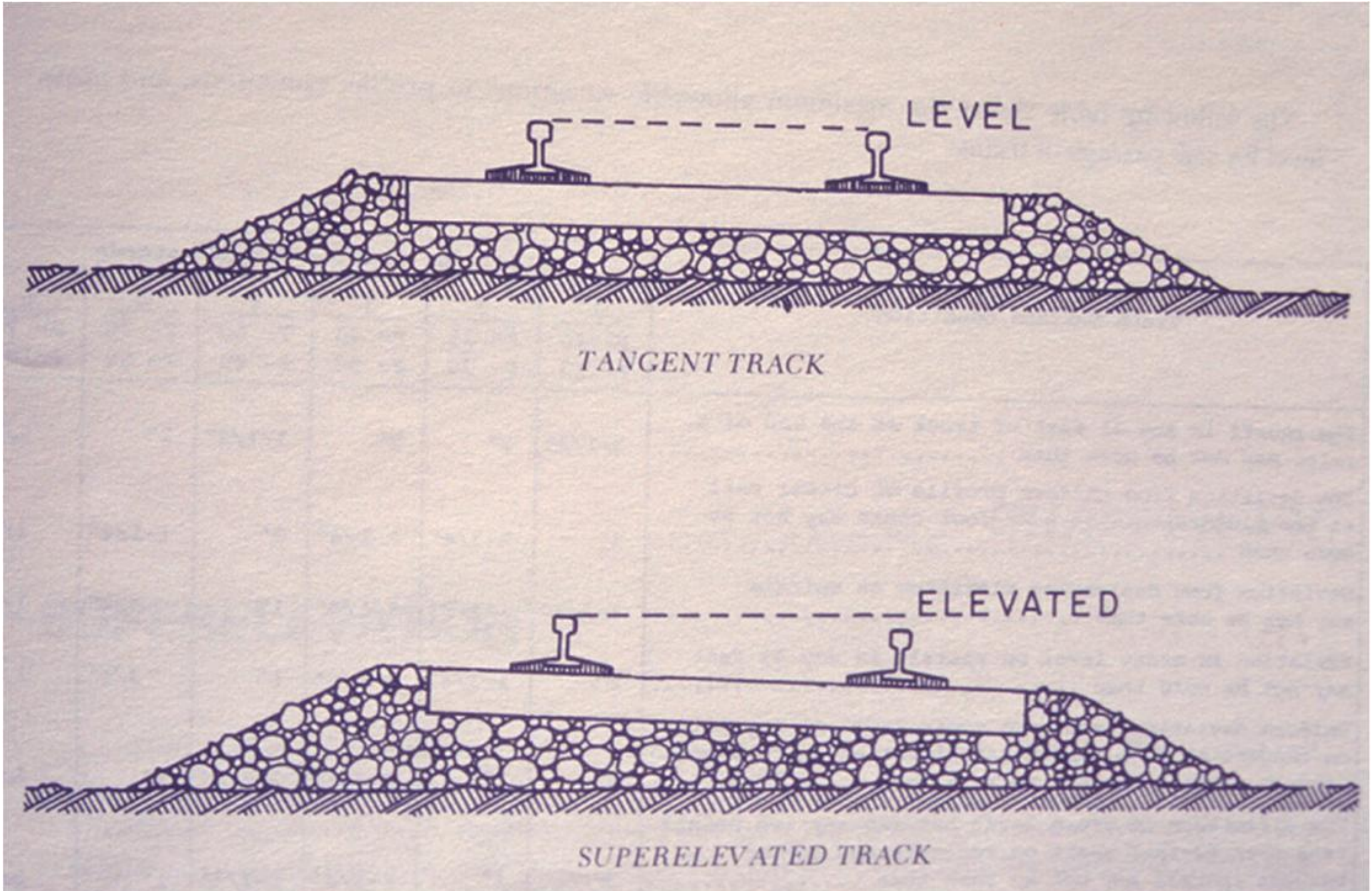


Elevation

$$E = 0.0007V^2D$$

- E= equilibrium elevation in inches
- V= speed in mph
- D= degree of curvature

• Superelevation



$$F_c = \frac{w\upsilon^2}{gR}$$

(F_c = Centrifugal Force)

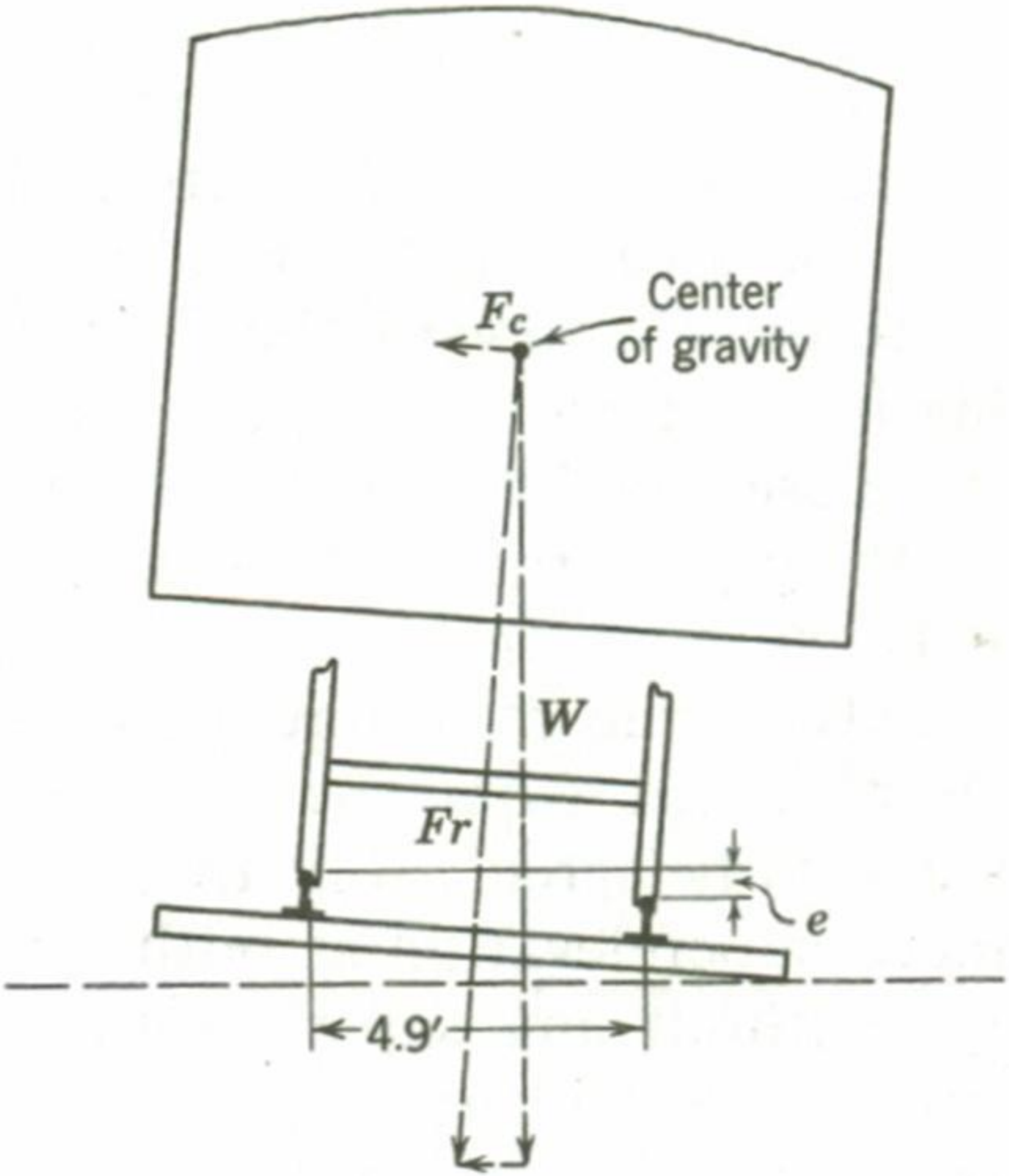
Where

w = weight of the car or locomotive in pounds

υ = speed in feet per second

R = radius of the curve in feet

g = acceleration due to gravity, 32.2 ft/sec/sec



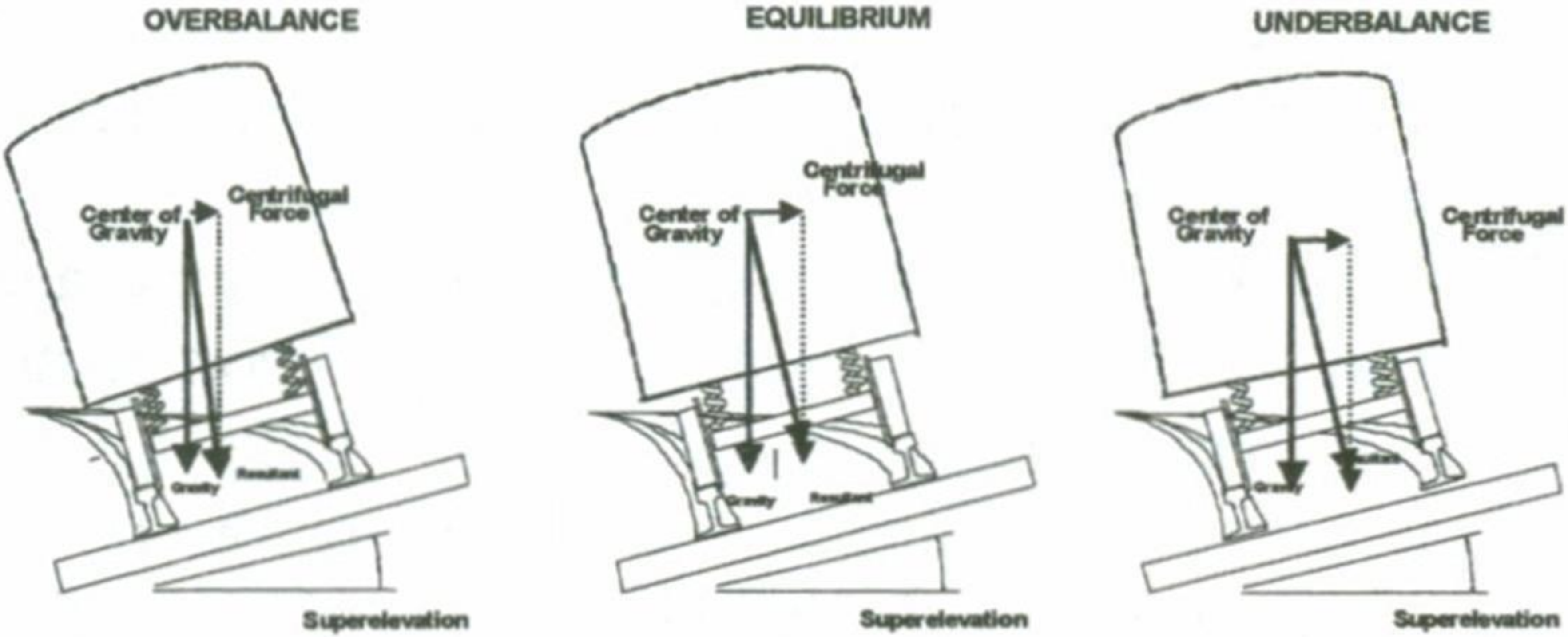
$$F_c = \frac{w\upsilon^2}{gR}$$

$$\frac{e}{F_c} = \frac{4.9}{W}$$

$$e = \frac{4.9w\upsilon^2}{gWR}$$

$$R \cong \frac{5730}{D_c}$$

$$e = 0.0007 D_c V^2$$



$$V_{max} = \sqrt{\frac{E_a + 3}{0.0007D}}$$

← Amount of Underbalance

V_{max} = Maximum allowable operating speed (mph).

E_a = Average elevation of the outside rail (inches).

D = Degree of curvature (degrees).

Figure 6-7 Overbalance, Equilibrium and Underbalanced

Actual super-elevation

- The maximum achievable actual super-elevation on high-speed track is considered: 6 in. - V=90 mph?
- It is common practice to limit actual super-elevation of a curve to 75% of it equilibrium elevation.
- For tracks where trains run at various speed, super-elevation shall be designed to prevent lower speed trains from experiencing overbalanced elevation.
- For high-speed train system with small amount of freight traffic, Ea equals to freight train speed limit-10 mph

Lateral acceleration

- 0.04 – 0.1 g
  - Influenced by vehicle, track characteristics and trip length

- In Europe, lateral acceleration < 0.05

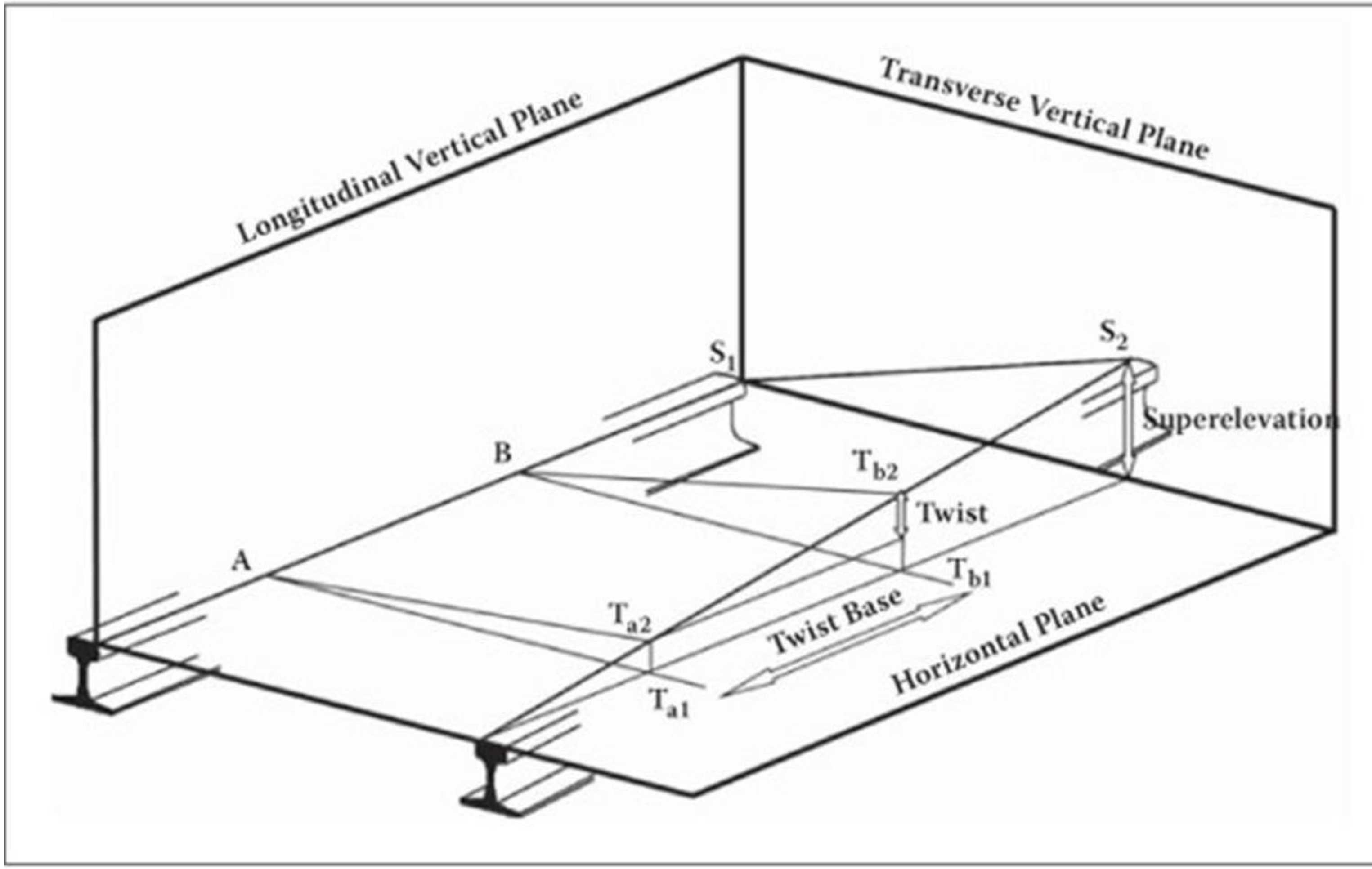


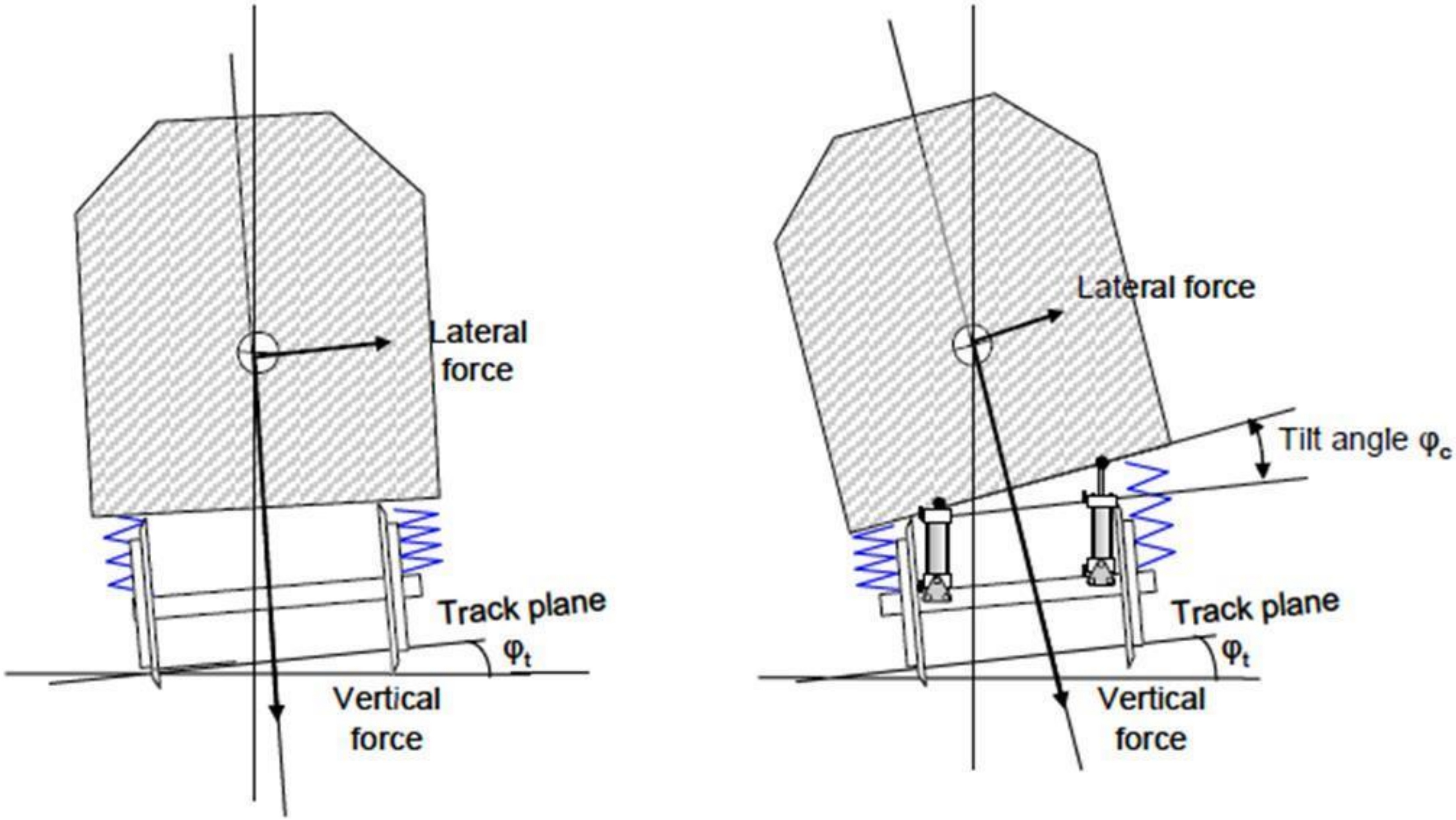
Figure 5 Track geometry in the transverse vertical plane

- http://www.scielo.org.za/scielo.php?pid=S1021-20192013000300003&script=sci_arttext

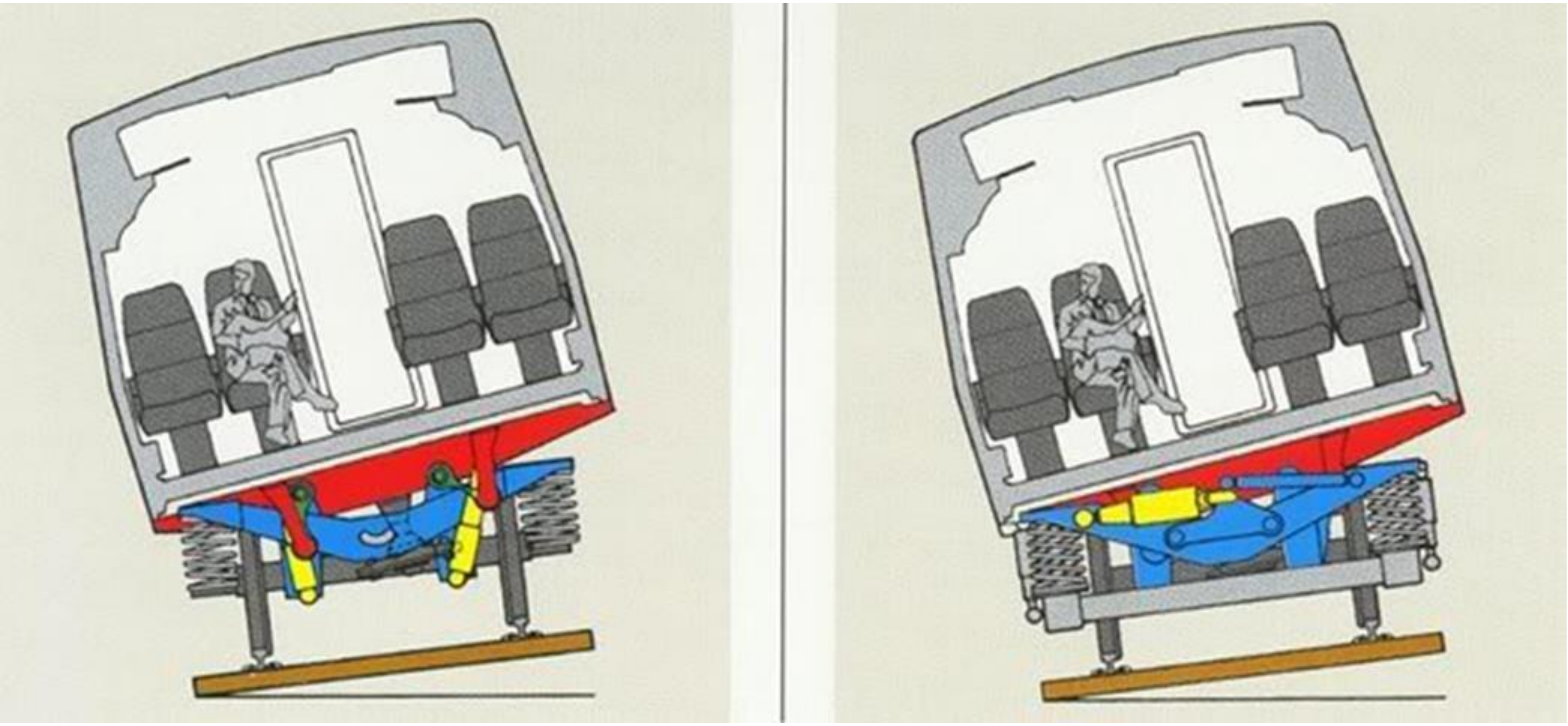
Unbalanced elevation

$$E_u = E - E_a$$

- Eu is positive, underbalanced < 4 in
  - FRA grants 5 inches for conventional passenger trains and passive tilt HS train
  - FRA grants 9 inches for active tilt HS train
- Eu is negative, overbalanced < 4 in



- http://www.gronataget.se/upload/publikadokument/tiltingtrains.pdf

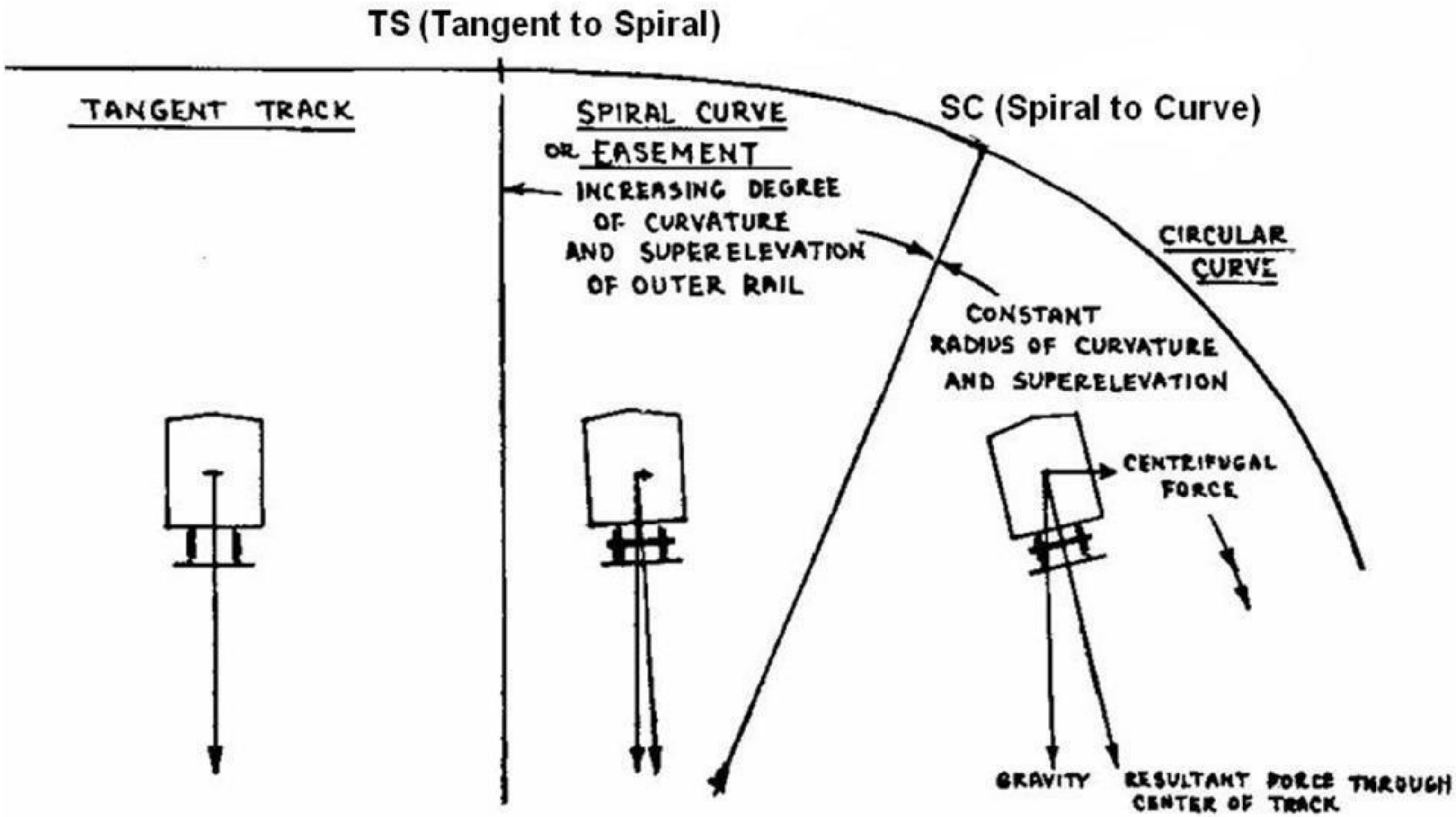


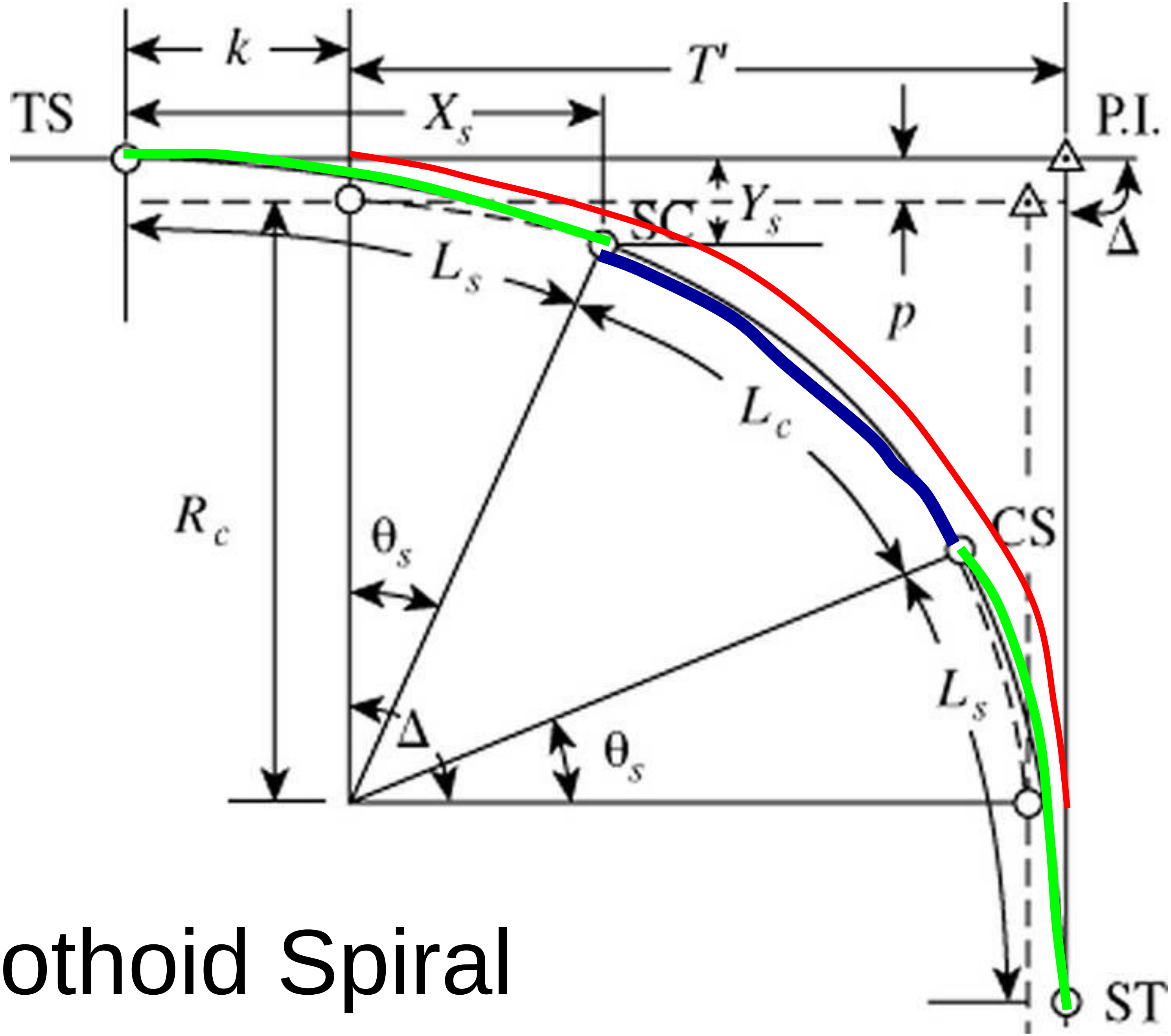
- http://www.dailykos.com/story/2011/01/16/936788/-Sunday-Train-Quiet-Progress-Edition-One-Superelevation-Cant-Deficiency

Clothoid spiral curve

- $L_s > 62\ E_a$ (ft)
- $60 < V \le 125$ mph, $L_s \ge 82.7 E_a$
- $V \ge 125$ mph, $L_s = 124 E_a$

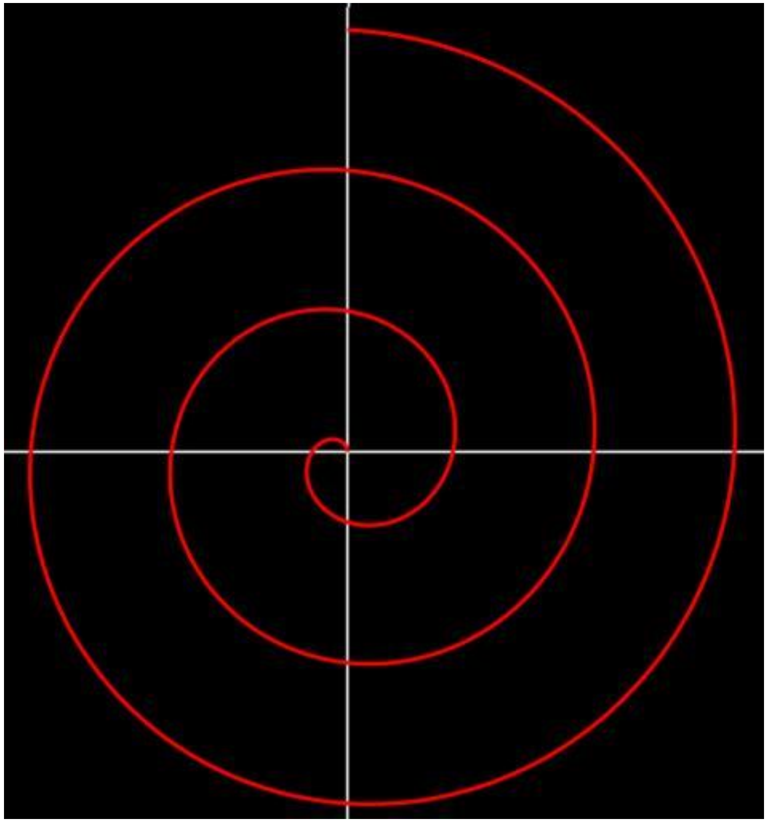
Spiral Transition Curves





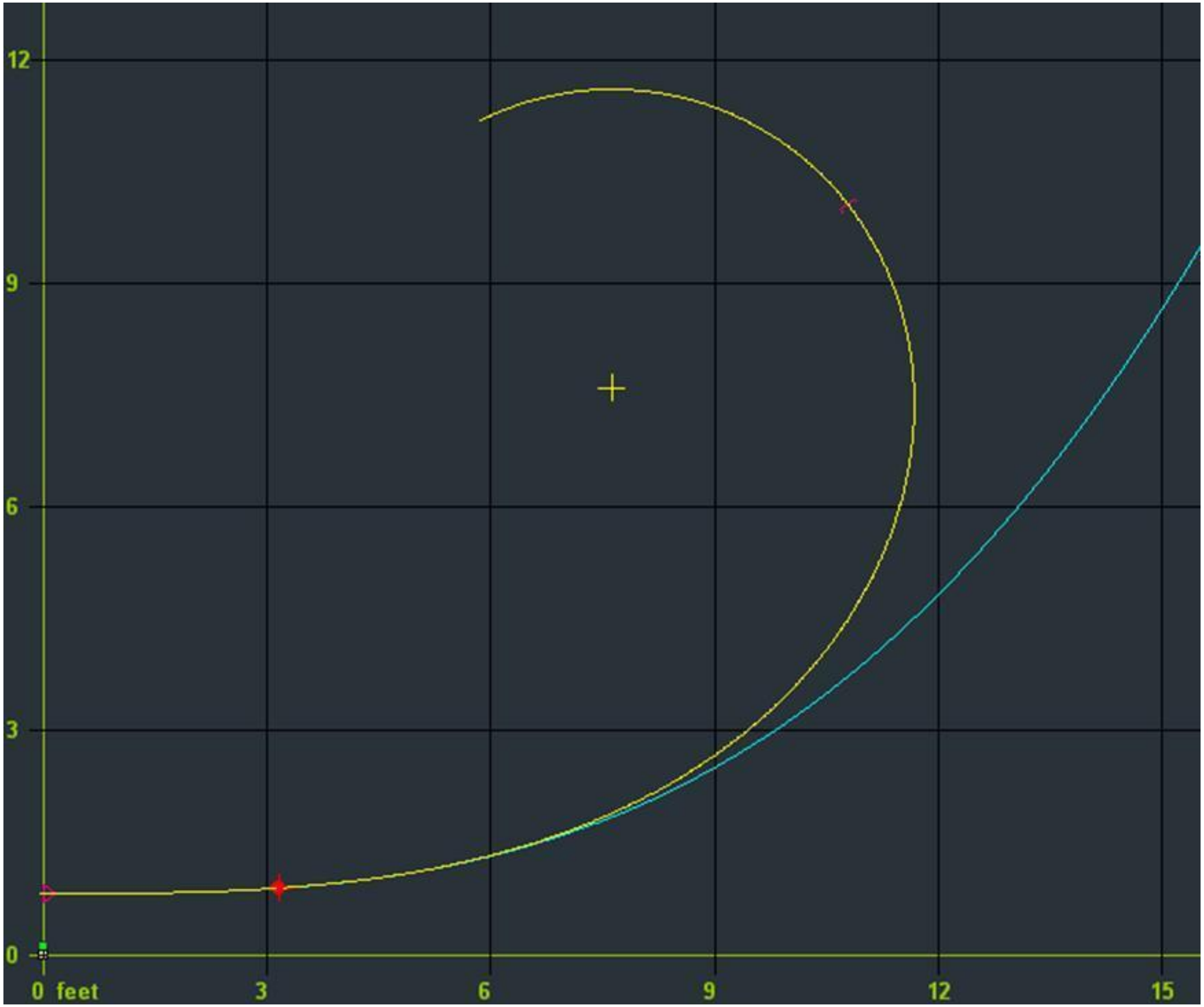
Clothoid Spiral

Spiral



$$\frac{\Delta R}{\Delta \theta} = C$$

http://en.wikipedia.org/wiki/Image:Archimedean_spiral.svg http://www.mathematische-basteleien.de/spiral.htm#Clothoide



http://www.templot.com/info/trans_gif.htm

Jerk Rate

- Jerk rate: the change in lateral acceleration with respect to time
- Clothoid transition spirals shall be long enough to ensure that a proper build up or runoff of lateral acceleration with respect to time is provided.
- Jerk rate ≤ 0.03 g/s
- When jerk rate < 0.01 g/s, no spiral curve required

Jerk rate (cont.)

- When the jerk rate is known:

$$L_s \geq vt = 1.46Vt$$

- Ls: spiral curve length in ft
- v: speed in ft/s
- V: speed in mph

$$t = \frac{\text{LateralAcceleration}}{\text{MaximimumAllowableJerkRate}} = \frac{a_L}{[(\Delta A_L)/(\Delta t)]_{\text{allowable}}}$$

Spiral curve – tilt rate

$$L_s \geq vt = 1.46Vt$$

$$t = \frac{\text{max tilt angle}}{\text{max tilt rate}}$$

- t= time required to tilt in second

Higher Order Spirals

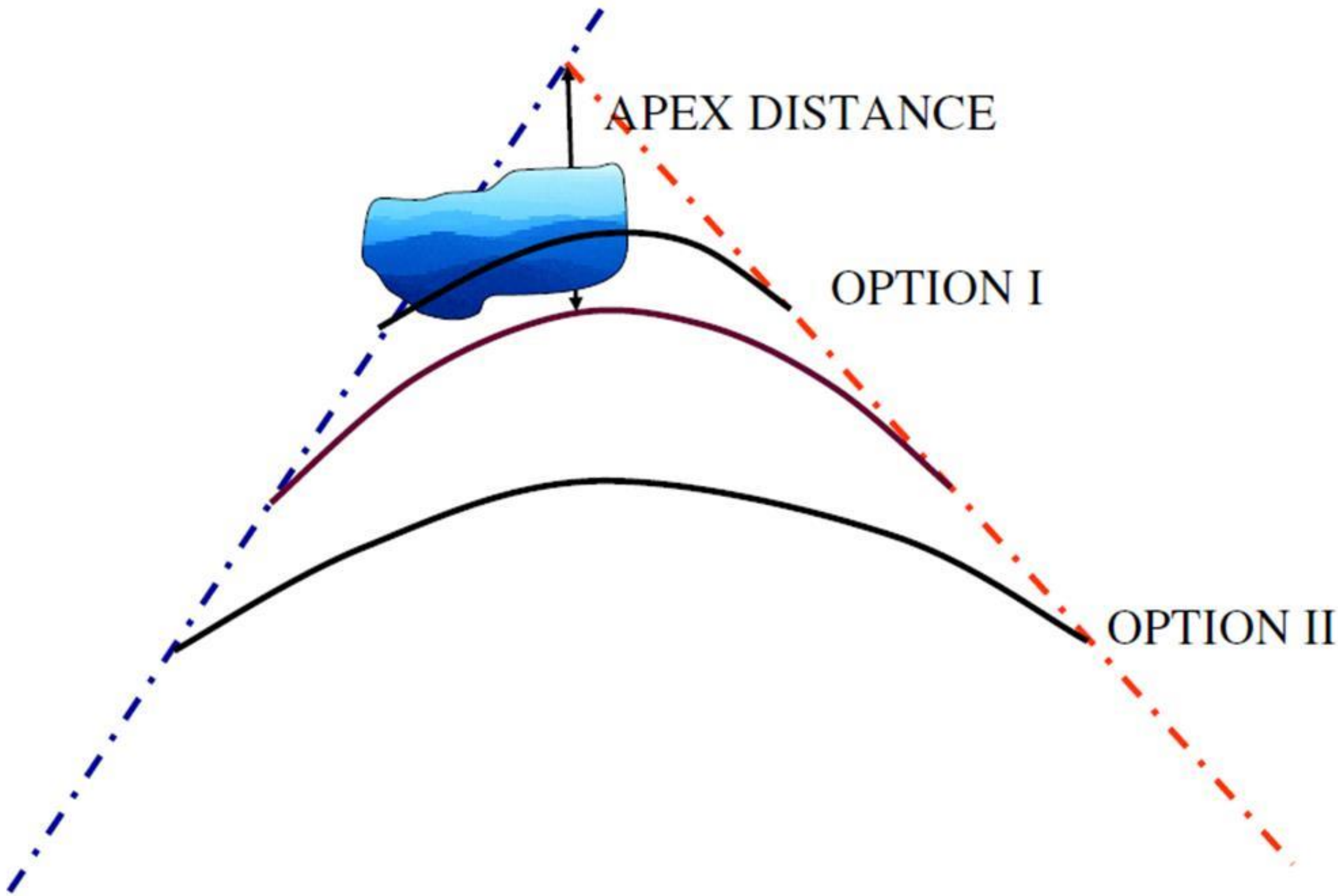
- Provide correct geometry that may be necessitated by high speeds and heavy axle loads

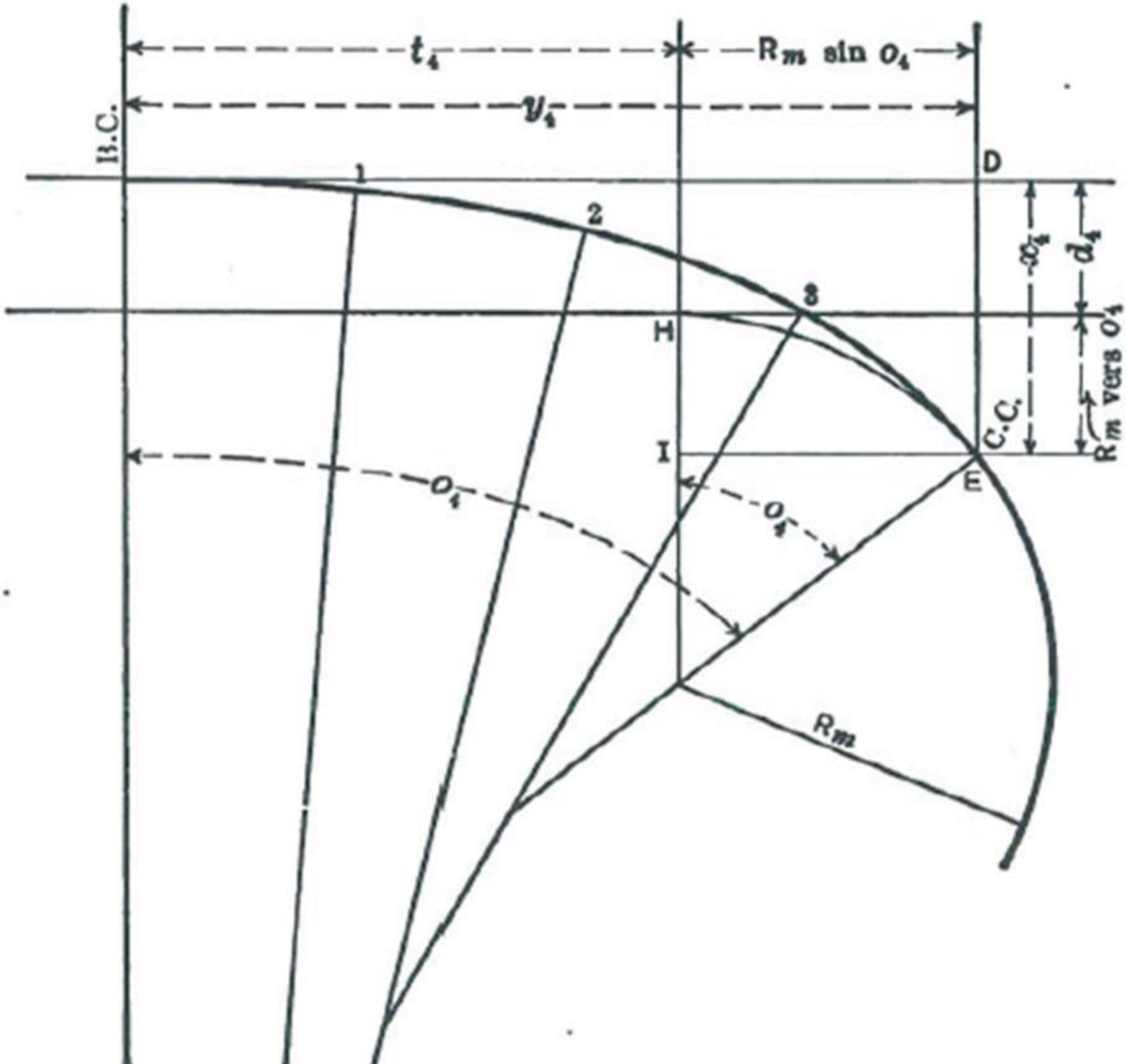
- 2^{nd} order curves: circular curves
- 3^{rd} order curve: clothoid curve
- 4^{th} and 5th order curve: S-shaped, parabolic, sine and cosine

- Not common practice for North American railroads

Why higher order transition curves?

- Provide correct geometry for both horizontal and vertical transitions to ensure comfortable operation of high-speed trains and decreases in track maintenance costs.
- At higher speeds abrupt changes in jerk may be considered to cause a reduction in the smooth operation of high-speed trains and passenger comfort.


APEX DISTANCE
OPTION I
OPTION II



t_4
R_m sin o_4
y_4
B.C.
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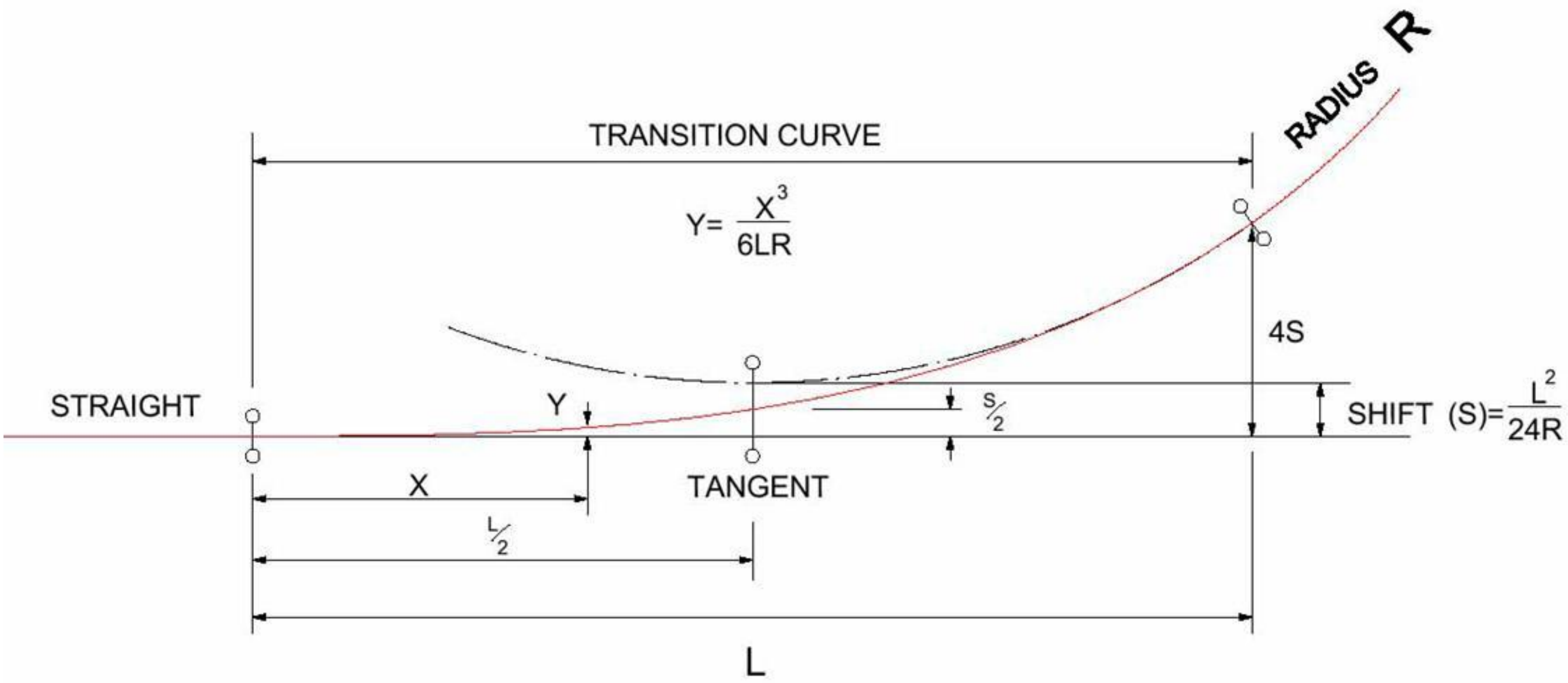


- http://www.mrol.com.au/Articles/Track/Cant_and_Transition_Design.aspx

Properties

- The shift between a straight and curve at the tangent point is $S = \frac{L^2}{24R}$
- The tangent point occurs halfway along the baseline of the transition.
- The radius at the tangent point is twice the radius of the curve.
- The offset at the end of the transition is four times the shift at the tangent point.
- At the tangent point the alignment of the transition passes exactly halfway between the straight and the curve, i.e., the offset from the baseline is half the shift.

Problems with Clothoid curve

- Along the transition curve, rotation movement starts suddenly at the starting point and it ends suddenly at the final point
- Superelevation diagram forms breaks at the starting and final points. At these points vertical acceleration shows sudden changes.
- As a result of the straight-line increase of the lateral acceleration, constant size rate of change of radial acceleration is obtained along the transition curve.

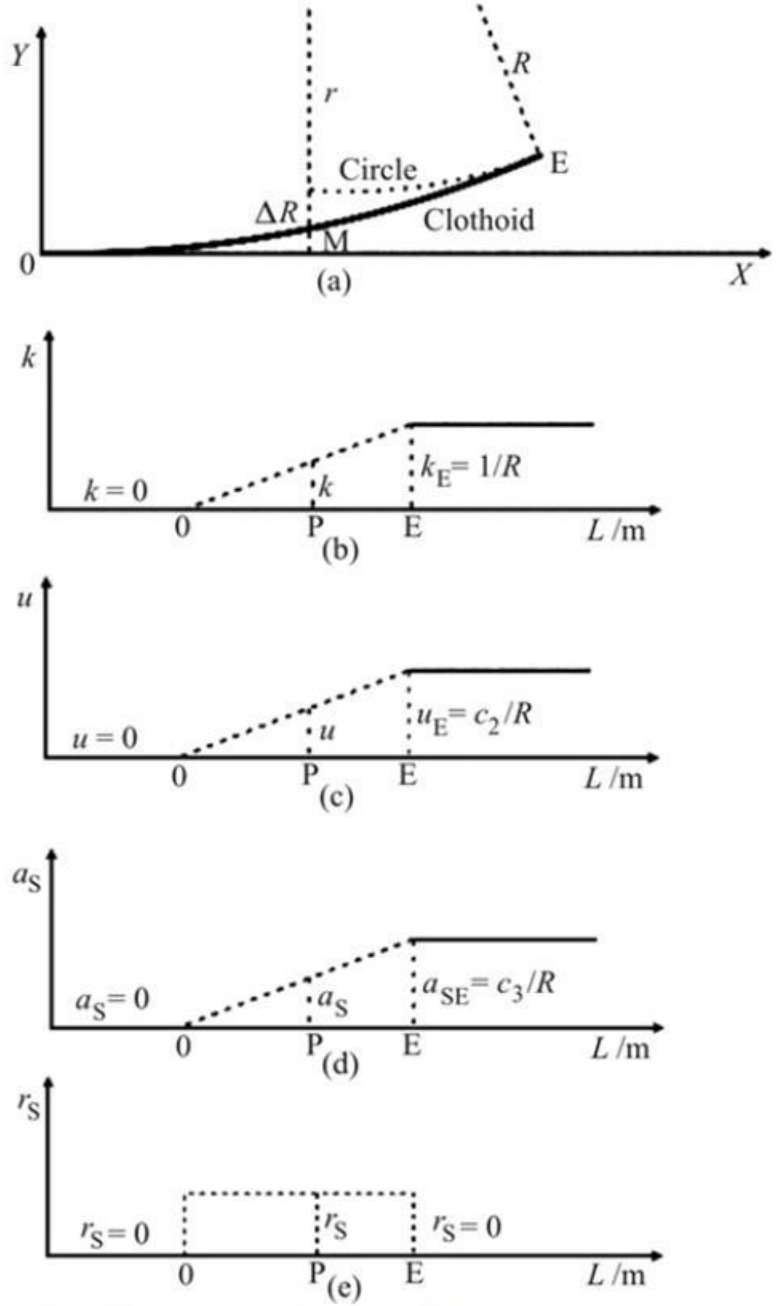


Figure 1 Diagrams of the clothoid: a) situation, b) curvature, c) superelevation, d) lateral acceleration, e) the rate of change of radial acceleration

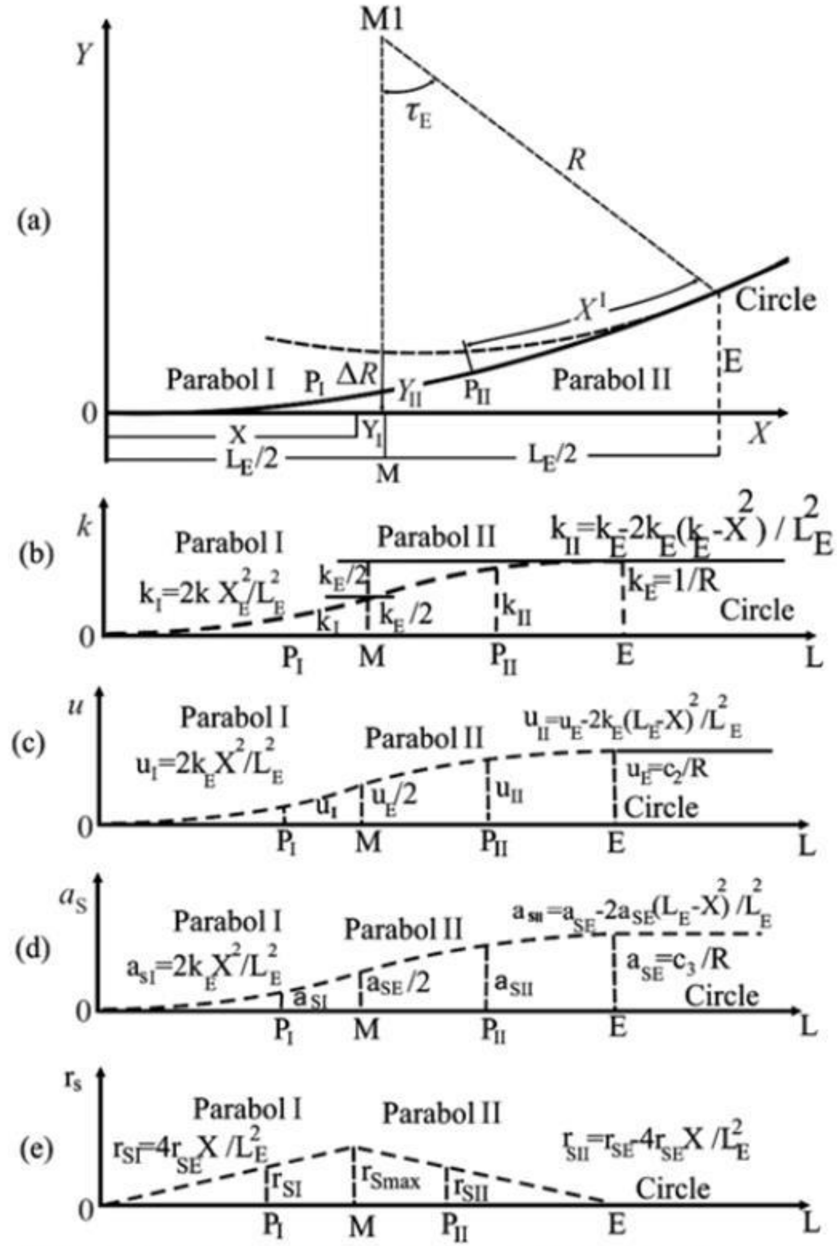


Figure 2 The diagrams of a fourth degree parabola as a transition curve a) Horizontal geometry b) Curvature c) Superelevation d) The lateral acceleration e) The rate of change of radial acceleration [6]

References:

- A. Pirti, M.A. Yucel, The fourth degree parabola as a transition curve, Tehnički vjesnik 19, 1(2012), 19-26
- V.B. Sood, Note on curve for railway
- L.T. Klauder, A better way to design railroad transit spiral, May 20, 2001
- Martin Lindahl, Track Geometry for High Speed Railway, 2001

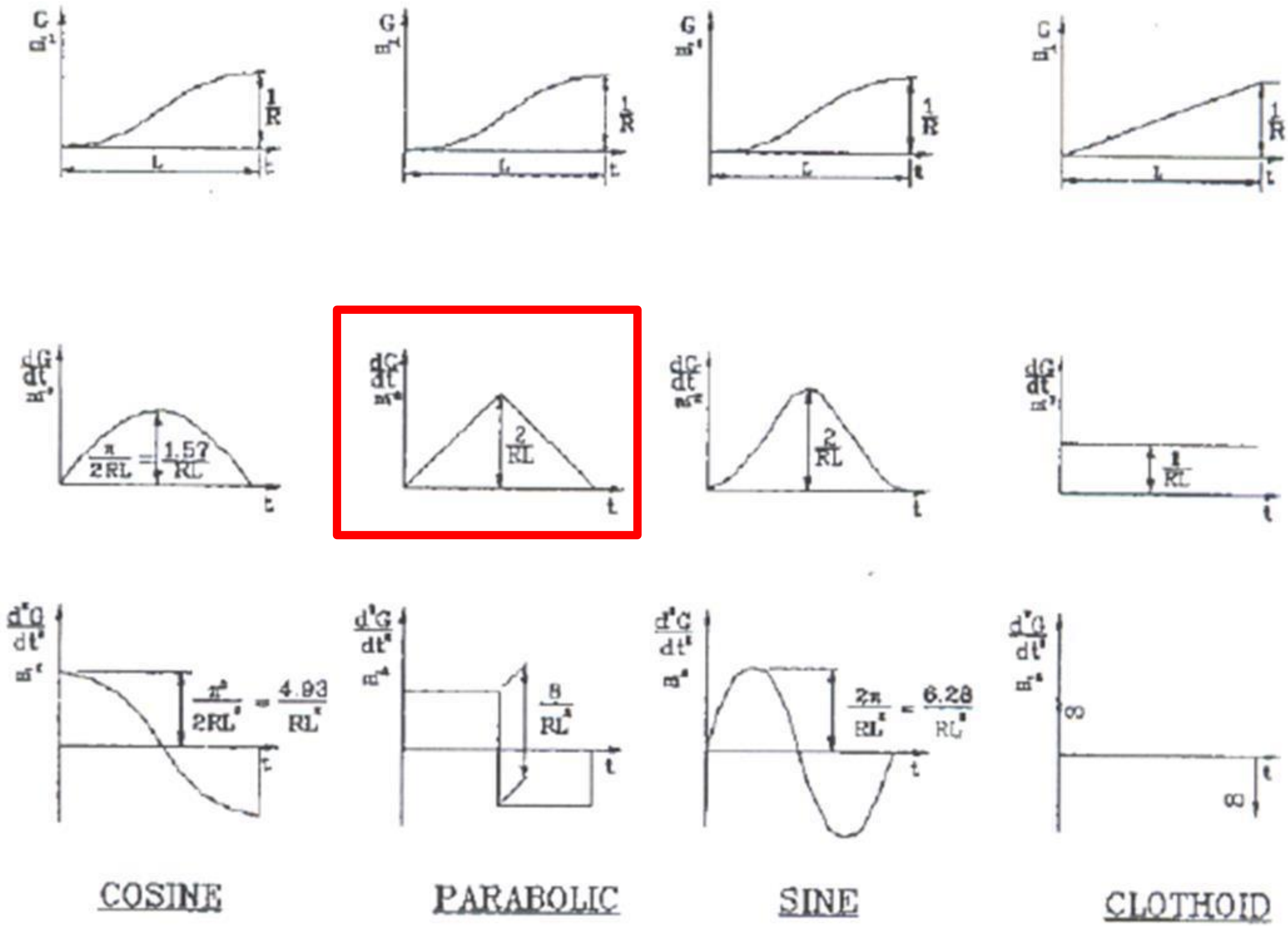


Figure 17-3-1. Common Spiral Transition Curve Geometries

Table 17-3-1. Comparison of Cosine, Parabolic and Sine Spiral to Clothoid Geometry

Geometric Features	Cosine	Parobolic	Sine	Clothoid
	Transition Geometry			
(dg/dt)max(m^2)	$\frac{\pi}{2}RL$	2/(RL)	2/(RL)	Broken function (1/RL)
(d^2G/dl^2)max(m^3)	4.93/(RL)	8/(RL^2)	6.28/(RL^2)	Theoretically Indefinite
The approximate value of shift (f)	L^2/(42.23R)	L^2/(48R)	L^2/(61.21R)	L^2/(24R)
The approximate value of "y" end coordinate (m)	0.149 (L^2/R)	0.146 (L^2/R)	0.141 (L^2/R)	0.16 (L^2/R)
The angle of the end tangent (J)	L/(2R)	L/(2R)	L/(2R)	L/(2R)
Increase of length compared to the clothoid geometry with identical shift (%)	33	41	60	-
Maximum lateral displacement compared to the clothoid, with identical shift	0.017f	0.025f	0.024f	-

Higher order spiral curve length

$L_r \geq 1.33 L_s$ for sine spiral

$L_r \geq 1.40 L_s$ for parabolic spiral

$L_r \geq 1.60 L_s$ for cosine spiral

Tolerances

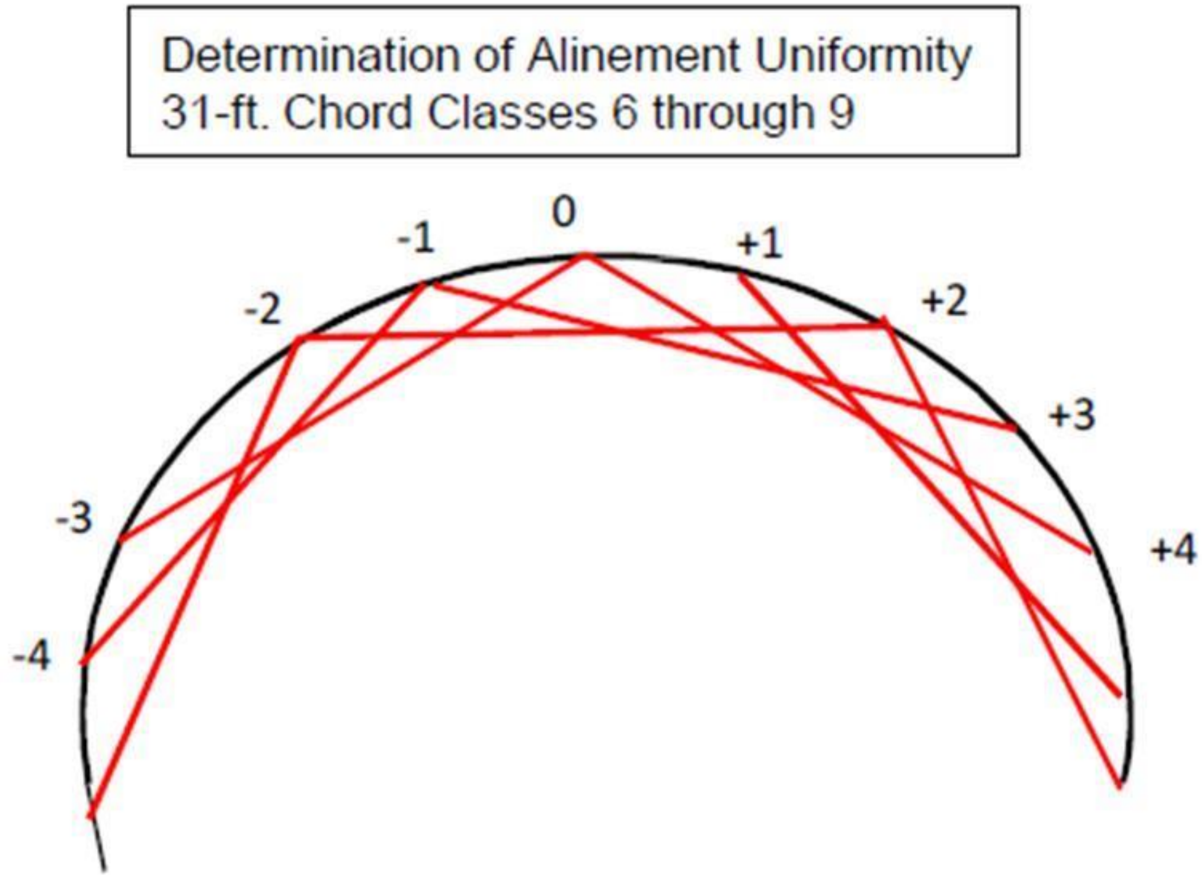
- Safety standard
  - Safety standards may not be exceeded **without a reduction of the speed limit (slow order) or suspension of service**.
- Maintenance tolerance
  - provide a measure of the track alignment such that maintenance activity can be scheduled and executed to ensure that the **track never degrades to Safety Standard limits**, passenger comfort is maximized, wear and tear on equipment is minimized, the track maintains its reliability and track maintenance remains economical.
- Construction tolerance
  - are the acceptable range of deviation **from the theoretical** (design) alignment that will allow maintenance standards to economically be achieved once the track is entered into service

[In miles per hour]

Over track that meets all of the requirements prescribed in this part for—	The maximum allowable operating speed for freight trains is—	The maximum allowable operating speed for for passenger-- trains is—
Excepted track.	10	N/A
Class 1 track.	10	15
Class 2 track.	25	30
Class 3 track.	40	60
Class 4 track	60	80
Class 5 track	80	90

Over track that meets all of the requirements prescribed in this subpart for—	The maximum allowable operating speed for trains[1] is—
Class 6 track	110 m.p.h.
Class 7 track	125 m.p.h.
Class 8 track	160 m.p.h.[2]
Class 9 track	200 m.p.h.

Alignment deviation measurement



Alignment deviation measurement (cont.)

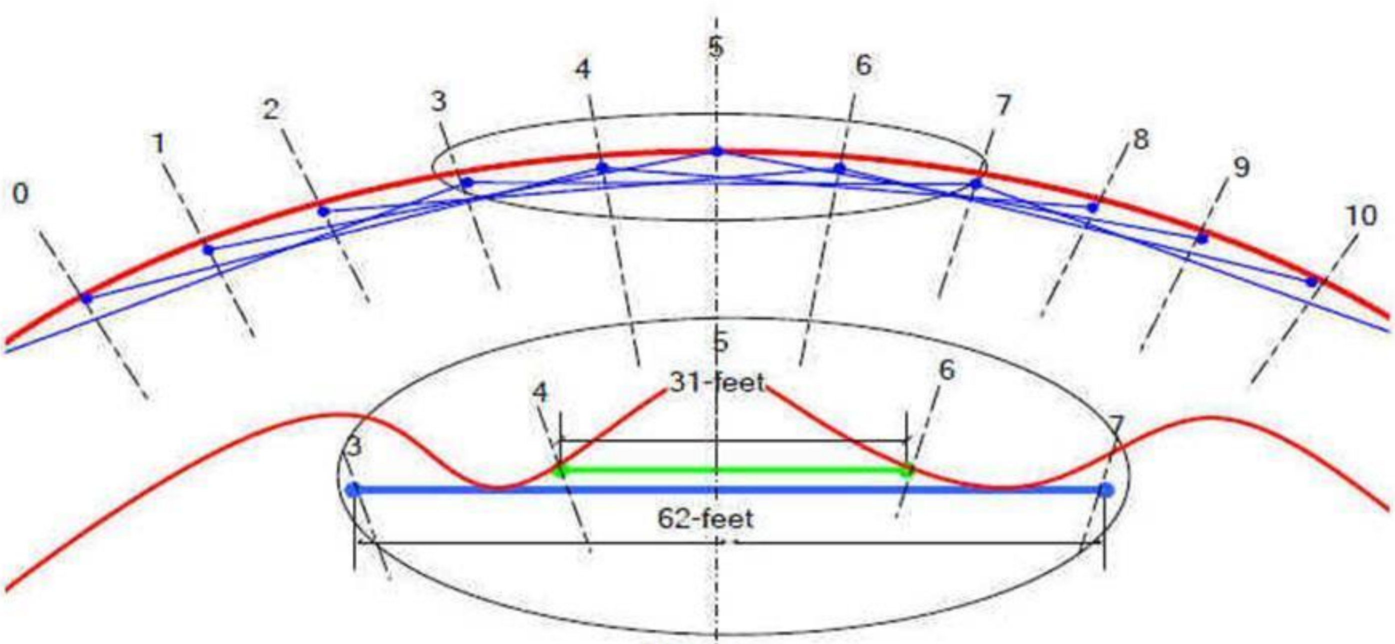


Figure 5

- http://www.railroadtraining.biz/TrackSafetyStandardsSubpartC.htm

Safety standards

327(b) Except as provided in paragraph (c) of this section, a single alinement deviation from uniformity may not be more than the amount prescribed in the following table:

Class of track	Tangent/ Curved track	The deviation from uniformity of the mid-chord offset for a 31-foot chord may not be more than—(inches)	The deviation from uniformity of the mid-chord offset for a 62-foot chord may not be more than—(inches)	The deviation from uniformity of the mid-chord offset for a 124-foot chord may not be more than—(inches)
Class 6 track	Tangent	½	¾	1 ½
	Curved	½	⅝	1 ½
Class 7 track	Tangent	½	¾	1 ¼
	Curved	½	½	1 ¼
Class 8 track	Tangent	½	¾	1
	Curved	½	½	¾

Maintenance tolerances

Alignment Maintenance Limits-Single Deviatioin			
Class of Track	The Deviation from Uniformity of the Mid-Chord Offset for a 31' Chord should not be more than (inches):	The Deviation from Uniformity of the Mid-Chord Offset for a 62' Chord should not be more than (inches):	The Deviation from Uniformity of the Mid-Chord Offset for a 124" Chord should not be more than (inches):
6	3/8	1/2	1
7	3/8	3/8	7/8
8	3/8	3/8	1/2
9	3/8	3/8	1/2

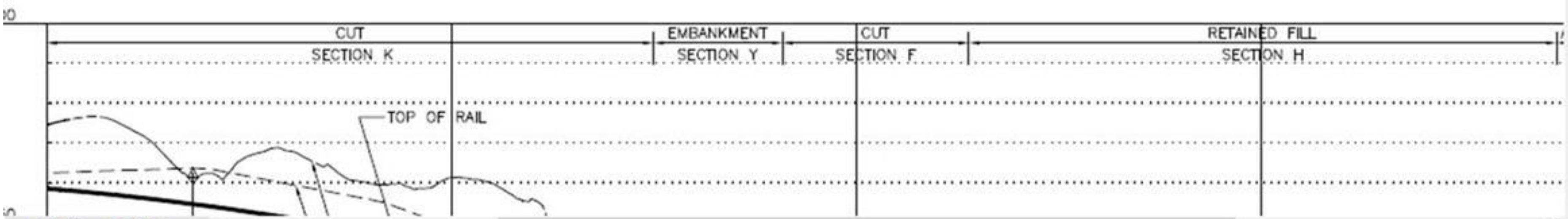
Alignment Maintenance Limits-Single Deviatioin			
Class of Track	The Deviation from Uniformity of the Mid-Chord Offset for a 31' Chord should not be more than (inches):	The Deviation from Uniformity of the Mid-Chord Offset for a 62' Chord should not be more than (inches):	The Deviation from Uniformity of the Mid-Chord Offset for a 124" Chord should not be more than (inches):
6	1/4	3/8	3/4
7	1/4	1/4	3/8
8	1/4	1/4	3/8
9	1/4	1/4	3/8

Construction Tolerances

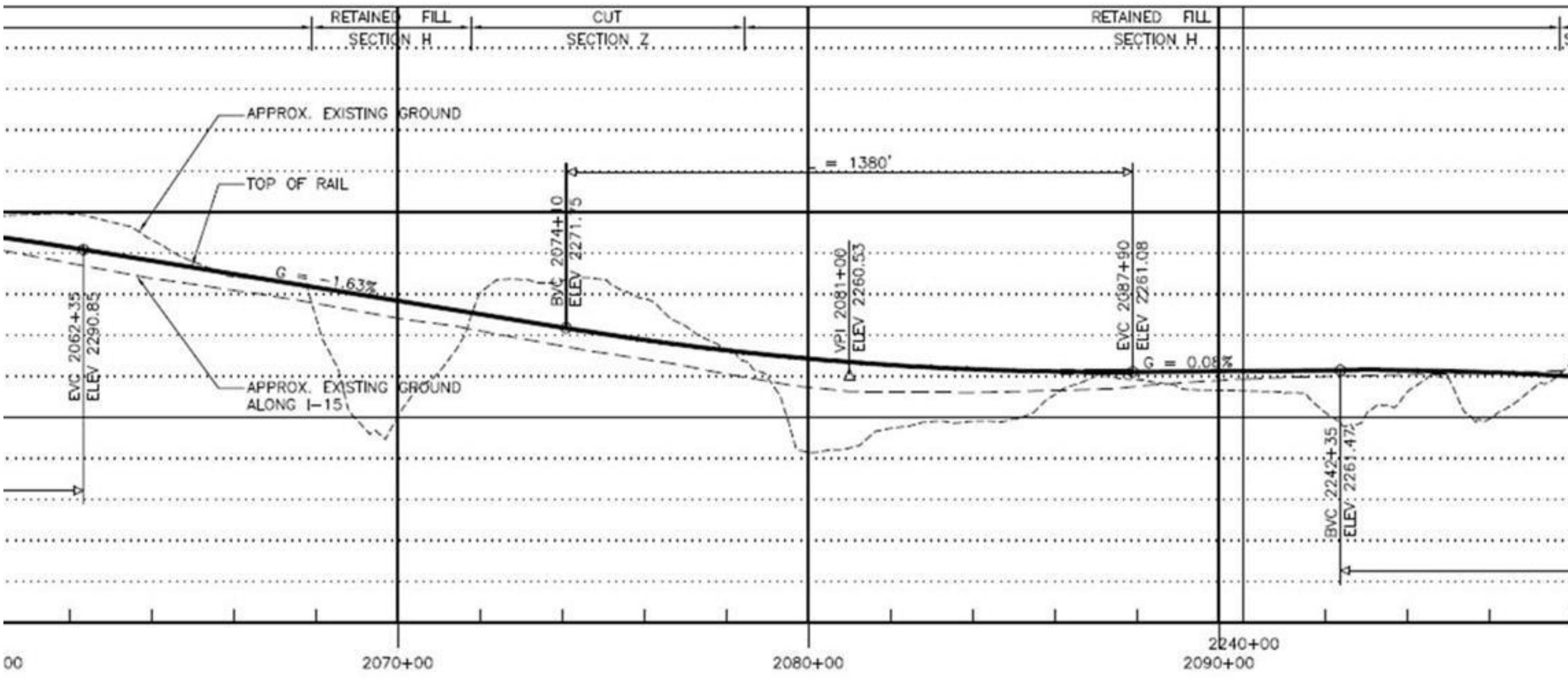
- The deviation of the designated mid-ordinate from a 62-foot chord should not be more that 1/8 inch for high-speed track up to 200 mph.
- For high-speed tracks where speeds will be greater than 200 mph, analysis of acceptable tolerances for construction should be performed.


MATCH LINE 2250+00
SEE DWG NO. C132C
CALTRANS R/W
EASEMENT
60'
DX2 TRACK
EASEMENT
125'
EASEMENT
65'
N
EASEMENT
0+00
2
4
6
8
2260+00
2
4
6
8
2270+00
2
4
6
8
2280+00
2
4
6
L = 2398.22'
S81°06'24.4"E
Ls = 1260'
15
TS DX1 2260+00.72
SC DX1 2270+60.72
DX1 TRACK

P L A N


CUT
SECTION K
EMBANKMENT
SECTION Y
CUT
SECTION F
RETAINED FILL
SECTION H
TOP OF RAIL

P L A N



PROFILE

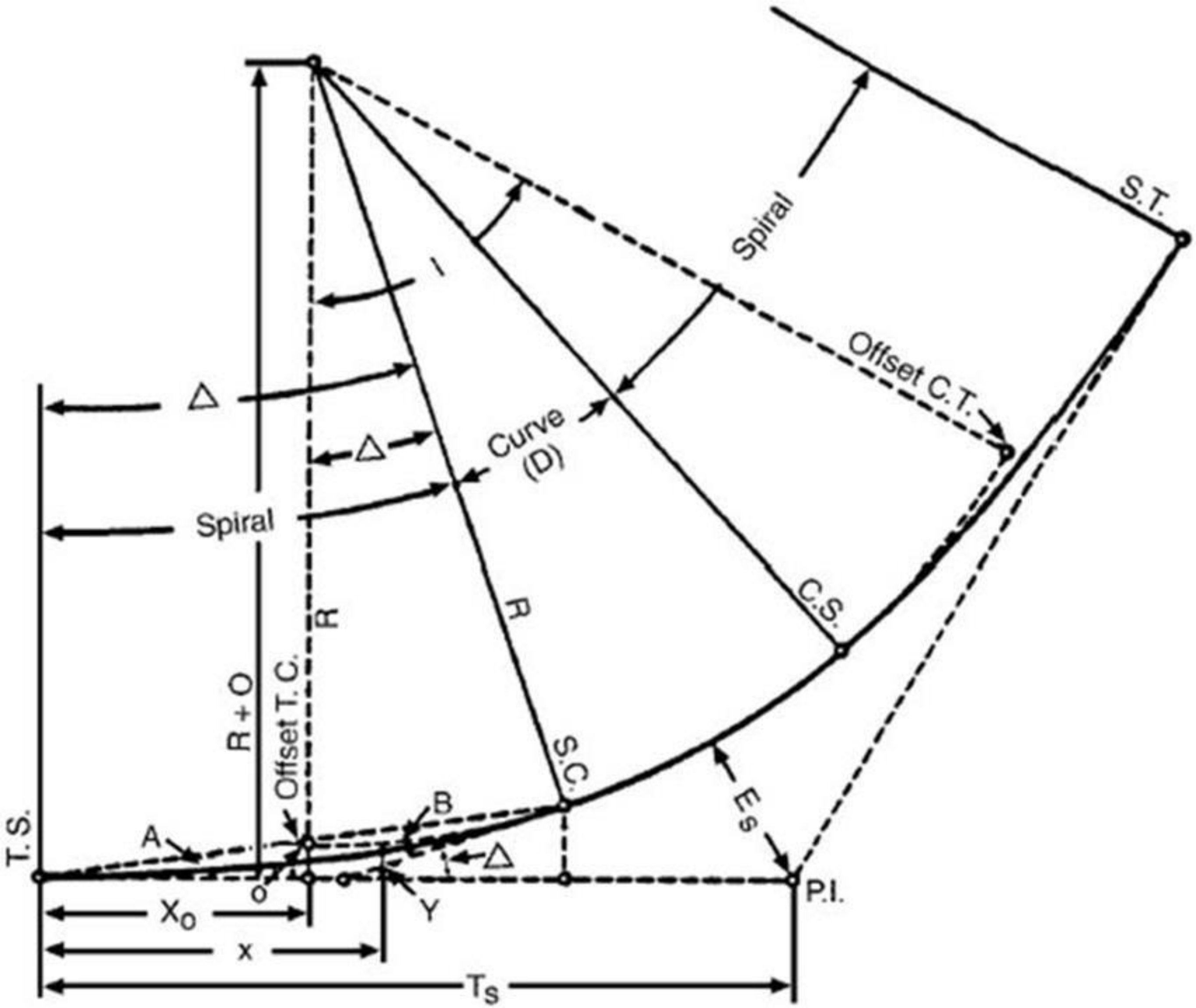


Figure 5-3-1. Spiral Applications

Figure 5-3-1 is a diagram illustrating the application of spirals at each end of a circular curve with the stationing from the left. The notation used in the formulas will be evident from this diagram and from the following:

- D = degree of circular curve
- d = degree of curvature of the spiral at any point
- l = Length from the T.S. or S.T., to any point on the spiral having coordinates x and y
- s = length l in 100-foot stations
- L = total length of spiral
- S = length L in 100-foot stations
- δ = central angle of the spiral from the T.S. or S.T. to any point on the spiral
- Δ = central angle of the whole spiral
- a = deflection angle from the tangent at the T.S. or S.T. to any point on the spiral
- b = orientation angle from the tangent at any point on the spiral to the T.S. or S.T.
- k = increase in degree of curvature per 100-foot station along the spiral

$$d = ks = \frac{kl}{100};\ D = kS = \frac{kL}{100}$$ EQ 4

$$\delta = \frac{1}{2}ks^2 = \frac{dl}{200};\ \Delta = \frac{1}{2}kS^2 = \frac{DL}{200}$$ EQ 5

$$a = \frac{1}{3}\delta = \frac{1}{6}ks^2;\ A = \frac{1}{3}\Delta = \frac{1}{6}kS^2$$ EQ 6

$$b = \frac{2}{3}\delta;\ B = \frac{2}{3}\Delta$$ EQ 7

$$y = 0.582\delta s - 0.00001264\delta^3 s$$ EQ 8

$$x = 1 - 0.003048\delta^2 s$$ EQ 9

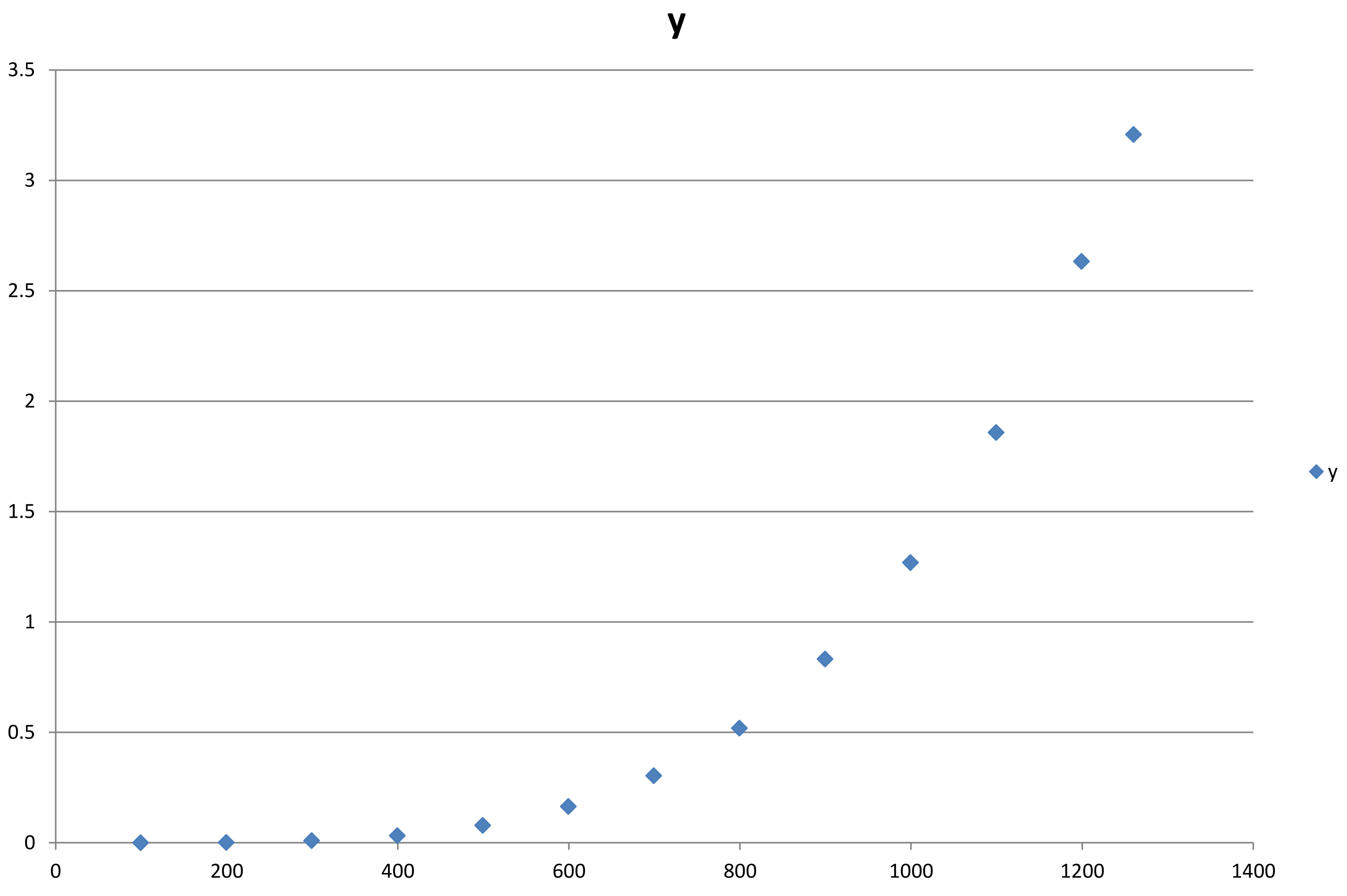
$$o = 0.1454\Delta S$$ EQ 10

$$Xo = \frac{1}{2}L - 0.000508\Delta^2 S$$ EQ 11

$$T_s = (R + o)\tan\left(\frac{I}{2}\right) + Xo$$ EQ 12

$$E_s = (R + o)\text{exsec}\left(\frac{I}{2}\right) + o$$ EQ 13

2260+00.72		2272+60.72			R = 50/sin(D/2)					
R=	10398									
D=	0.551065		degree of curvature		k	D=	0.551029			
Ls=	1260				s					
					l	s	k	delta	x (ft)	y (ft)
1	2260	0.72	226000.7						x	y
2	2261		226100	99.28	99.28	0.9928	0.000434	0.000214	99.28	0.000124
3	2262		226200	100	199.28	1.9928	0.000872	0.001731	199.28	0.002007
4	2263		226300	100	299.28	2.9928	0.001309	0.005862	299.28	0.01021
5	2264		226400	100	399.28	3.9928	0.001746	0.01392	399.28	0.032347
6	2265		226500	100	499.28	4.9928	0.002184	0.027217	499.28	0.079086
7	2266		226600	100	599.28	5.9928	0.002621	0.047064	599.28	0.164151
8	2267		226700	100	699.28	6.9928	0.003058	0.074775	699.2799	0.30432
9	2268		226800	100	799.28	7.9928	0.003496	0.11166	799.2797	0.519423
10	2269		226900	100	899.28	8.9928	0.003933	0.159033	899.2793	0.832348
11	2270		227000	100	999.28	9.9928	0.00437	0.218205	999.2785	1.269036
12	2271		227100	100	1099.28	10.9928	0.004808	0.290488	1099.277	1.858481
13	2272		227200	100	1199.28	11.9928	0.005245	0.377194	1199.275	2.632732
14	2272	60.72	227260.7	60.72	1260	12.6	0.005511	0.437436	1259.993	3.207791


y
3.5
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000
1200
1400
y

HSR – Geometric Design

Vertical Curve

Vertical Curves

- Curves that transition between different grades
- Necessary for smooth train operation
- More difficult to construct than uniform grades

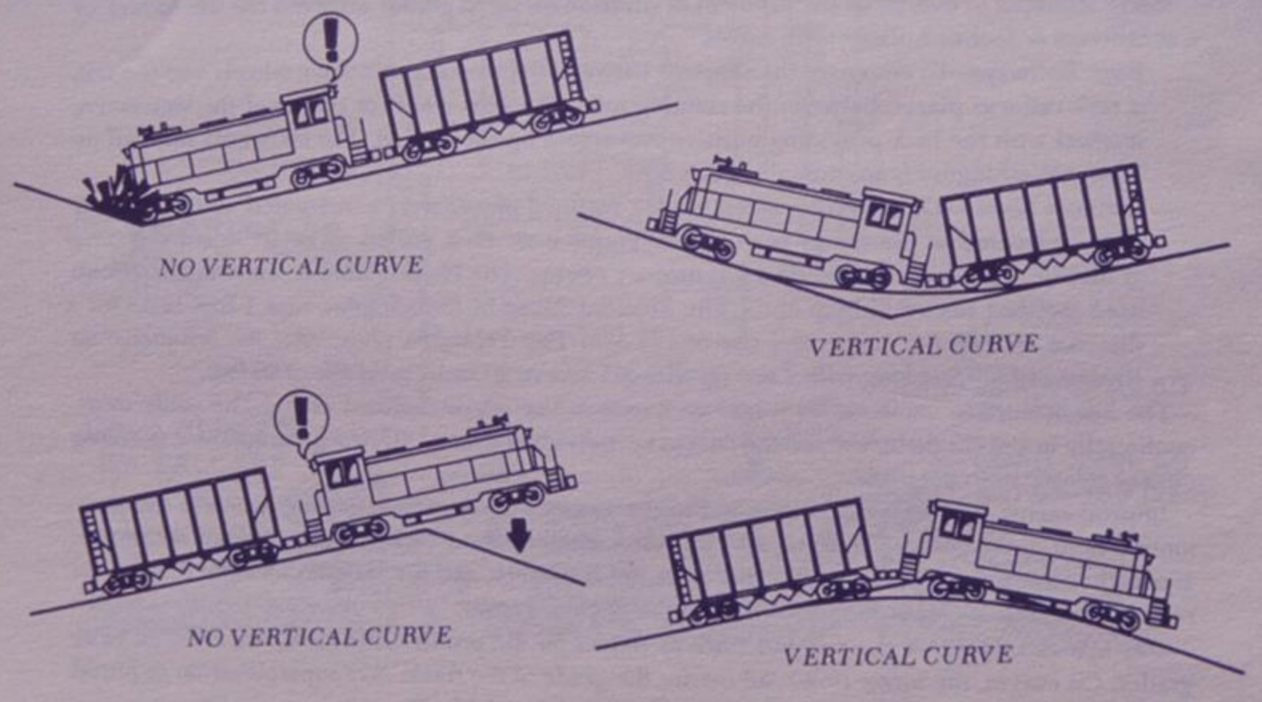
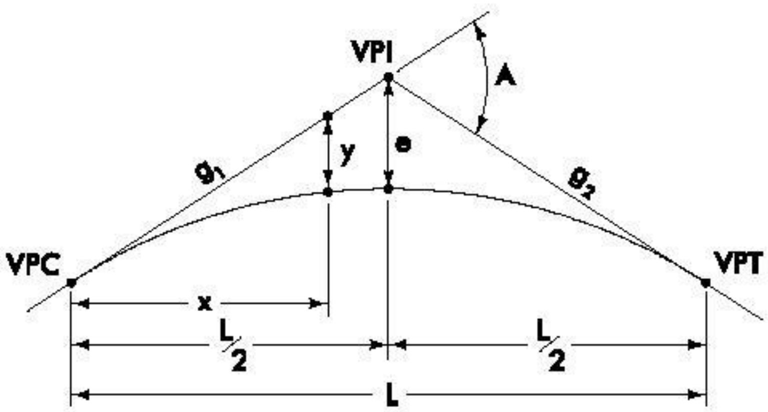


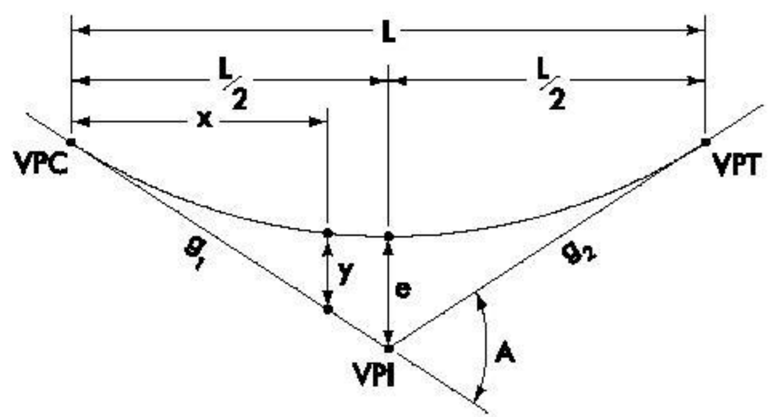
FIG. 11-6 EFFECT OF CHANGE IN GRADE

Vertical Curves

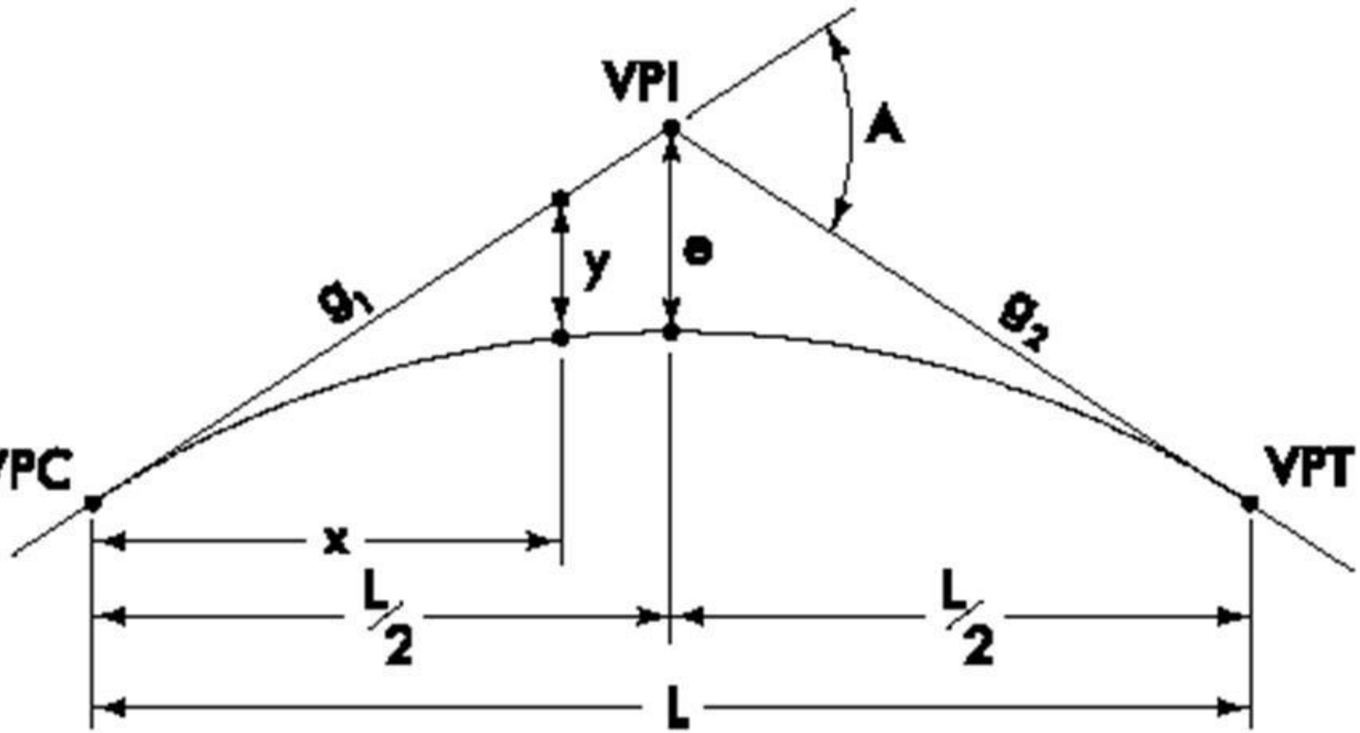
- Parabolic in nature
- Sag - concave upwards, valley
- Summit - concave downward, hills



Crest

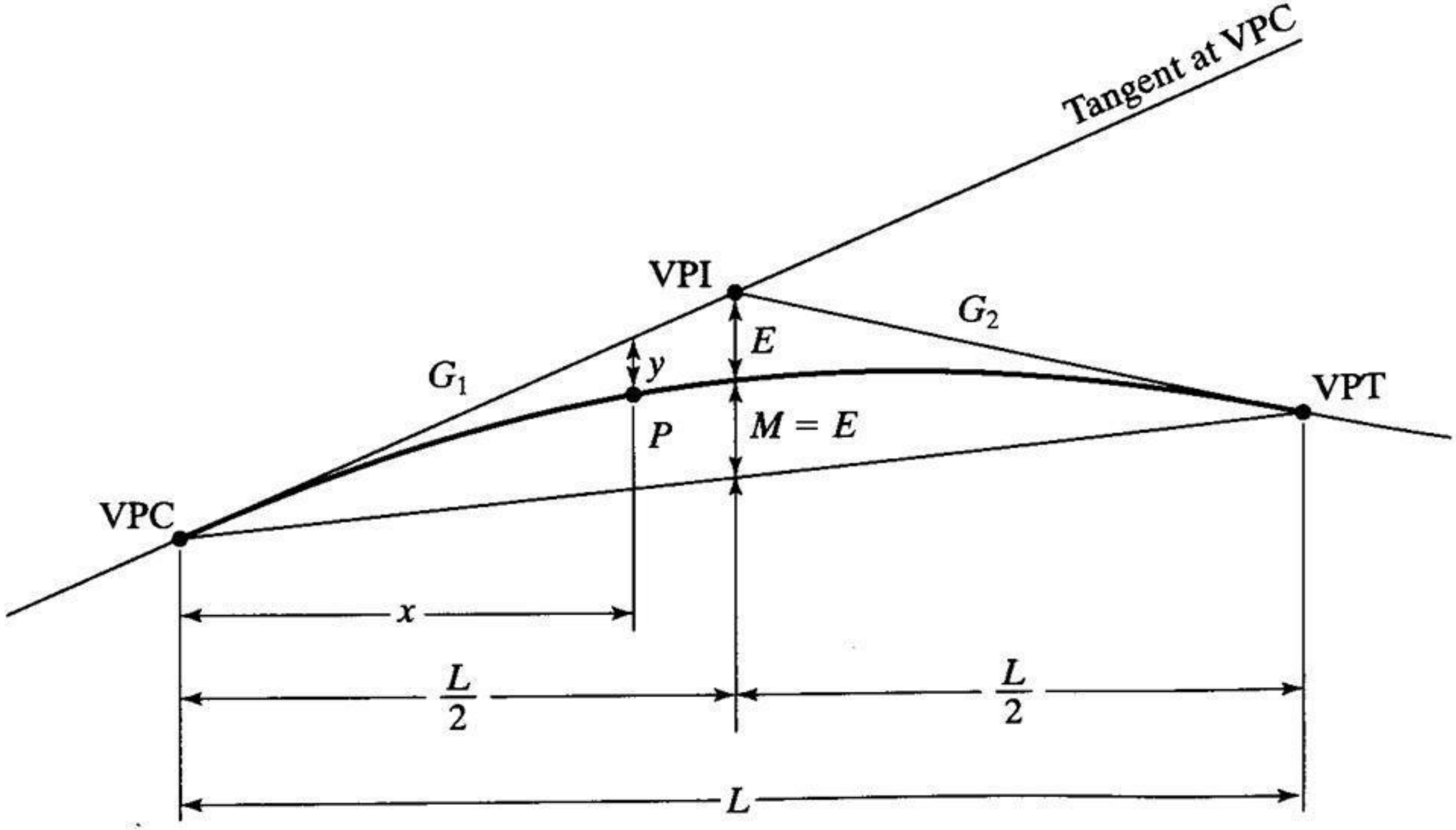


Sag



Crest

Vertical Curve as a Parabola



Vertical Curve as a Parabola (cont.)

$Y=a+bx+cx^2$

where Y= the elevation of the vertical curve at a distance x feet from the VPC

a = the elevation of VPC (feet)

b = the slope of the entering tangent (ft/ft) $=G_1$

c = the rate of change in grade

Vertical Curve as a Parabola (cont.)

- dY/dx=b+2cx
  - X=0, the slope is G_1. Therefore, $b=G_1$
- $d^2Y/dx^2=2c$, the rate of change of the slope
  - $2c=(G_2-G_1)/L$
- High point

$$G_1 + \frac{G_2 - G_1}{L} x = 0$$

$$x_{hi/lo} = \frac{-G_1}{G_2 - G_1} * L = L * \frac{G_1}{G_1 - G_2}$$

Vertical Curve as a Parabola (cont.)

- offset: cx^2

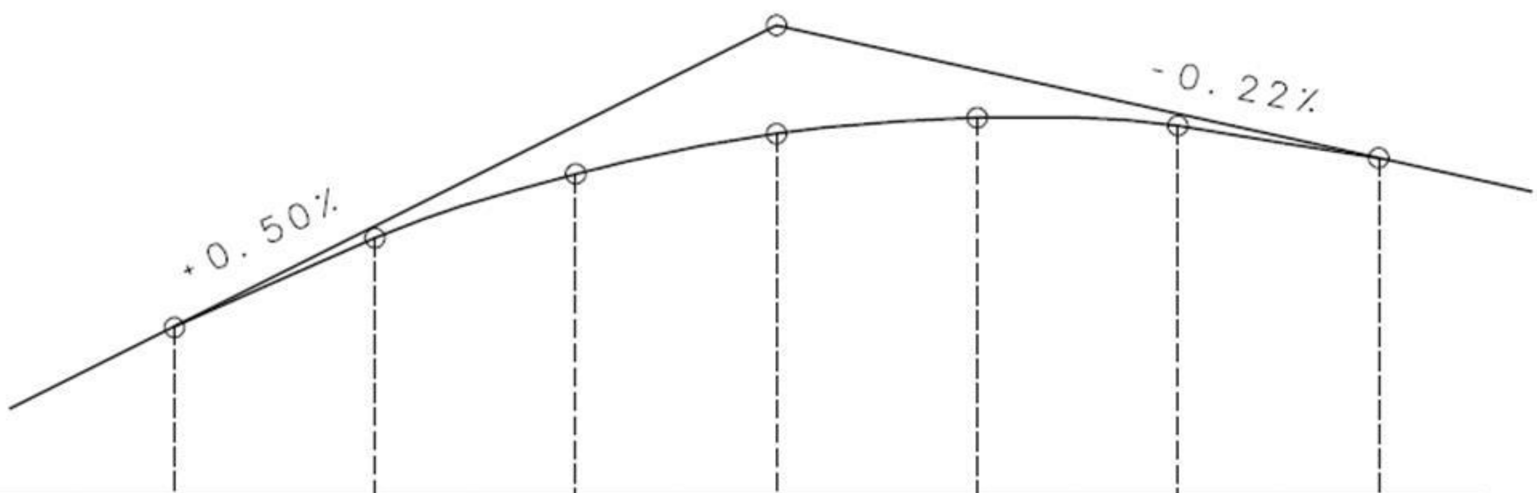
$$y = \frac{|G_2 - G_1|}{2L} x^2 = \frac{|G_2 - G_1| * L}{2} \left(\frac{x}{L} \right)^2 = \frac{A * L}{2} \left(\frac{x}{L} \right)^2 = \frac{Ax^2}{2L}$$

Convention: $A = G_2 - G_1$

Vertical Curves

- R = D/L
  - R= rate of change per station (standard measurement of vertical curves)
  - D= change in grades
  - L= length of vertical curve (in stations)
- R should equal 0.05 for sags and 0.10 for summits (AREMA)

Example of calculations for a vertical curve



Station	10+00	11	12	13	14	15	16+00
Elevation	90.00	90.50	91.00	91.50	91.28	91.06	90.84
Correction	0.00	0.06	0.24	0.54	0.24	0.06	0.00
Elevation	90.00	90.44	90.76	90.96	91.04	91.00	90.84
Percent Grade	+.44	+.32	+.20	+.08	-.04	-.16	

Source: http://www.bnsf.com/tools/fieldengineering/pdf/IndyTrkStds_1007a.pdf

- This method sometimes results in longer vertical curves than really necessary
- Doesn’t take into account train speed or vertical acceleration

- Properly designed vertical curves minimize adverse effects on coupler angles, vertical acceleration
- Rolling stock suspension, ride quality, and train dynamics

New AREMA method

$$L = \frac{D * V^2 * K}{A}$$

- L= Length of vertical curve
- A= vertical acceleration
  - AREMA recommends a value of 0.10 and 0.60 for freight and passenger operations respectively for both sag and summit curves.
- D= difference in rates of grades
- K=2.15
- V=train velocity

High Speed Rail

$$L = \frac{D \times V^2 \times K}{A}$$

- A = vertical acceleration in feet/sec/sec (ft/Sec2); A = 0.10 for freight operations; 0.60 for passenger and transit operations)
- D = Absolute value of the difference in rate of grades expressed as a decimal
- K = 2.15 conversion factor to give L in feet
- L = Length of vertical curve in feet
- V = Speed of the train in miles per hour

SECTION 3.6 VERTICAL CURVES (2002)

a. Vertical curves as calculated in item (f) below should be used to connect all changes in gradients.

b. The length of vertical curve is determined by changes in gradient, vertical acceleration and the speed of the train.

c. The purpose of the vertical curve is to ease the change of the gradients in order to reduce coupler and diaphragm binding and eliminate the danger of breaking trains in two as a direct result of train action. In addition, the proper vertical curve will provide for passenger comfort on passenger trains. Vertical curves should be designed as long as physically and econmically possible.

d. A vertical curve which is concave upwards shall be denoted as a sag. A vertical curve which is concave downwards shall be denoted as a summit.

e. The vertical curve may be either circular or parabolic in shape.

f. The **minimum** length of the vertical curve for both sags and summits is determined by the following formula (except that in no case should the length of the vertical curve be less than 100 feet long):

$$L = \frac{D \times V^2 \times K}{A}$$

Where: A = vertical acceleration in feet/sec/sec (ft/sec^2)

D = Absolute value of the difference in rates of grades expressed as a decimal

K = 2.15 conversion factor to give L in feet

L = Length of vertical curve in feet

V = Speed of the train in miles per hour

Example Calculation for Passenger and Transit Operations

Sag curve with 0.50% descending grade meeting a 0.50% ascending grade. Maxiumum design speed is 75 MPH.

A = 0.60 feet/sec/sec vertical acceleration (Passenger and Transit)

D = Absolute value of ((-.005) - (+.005)) = 0.01

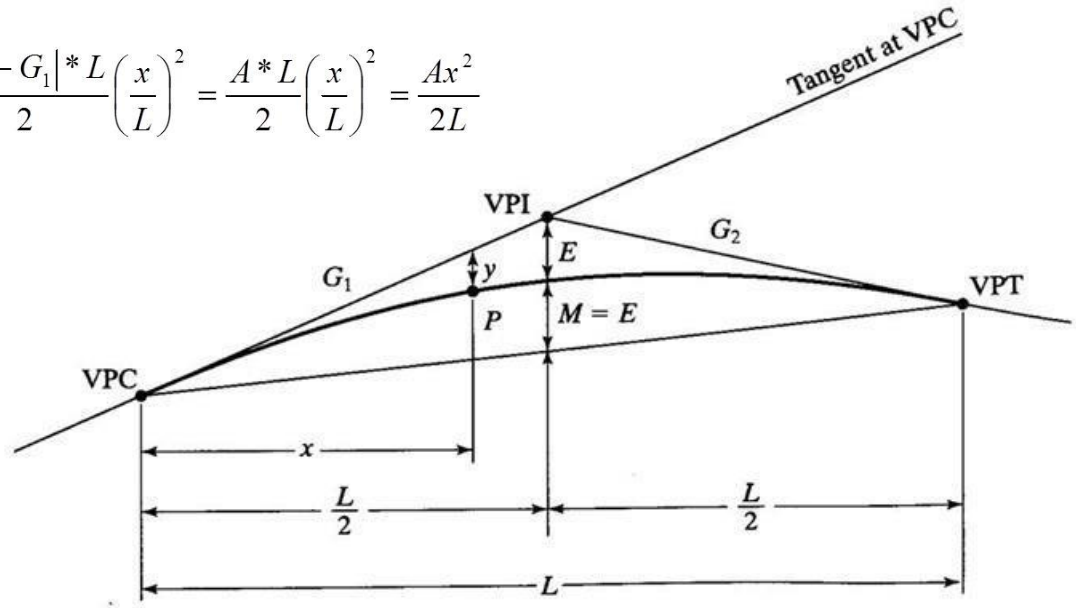
K = 2.15 conversion factor to give L in feet

V = 75 MPH design speed

$$L = \frac{D \times V^2 \times K}{A} = \text{Length of vertical curve in feet}$$

$$L = \frac{(0.01) \times (75\text{MPH})^2 \times 2.15}{0.60 \ \text{feet/sec/sec}} = 201.56 \text{ feet} \quad \text{say } 205 \text{ feet}$$

$$y = \frac{|G_2 - G_1|}{2L}x^2 = \frac{|G_2 - G_1| * L}{2}\left(\frac{x}{L}\right)^2 = \frac{A * L}{2}\left(\frac{x}{L}\right)^2 = \frac{Ax^2}{2L}$$



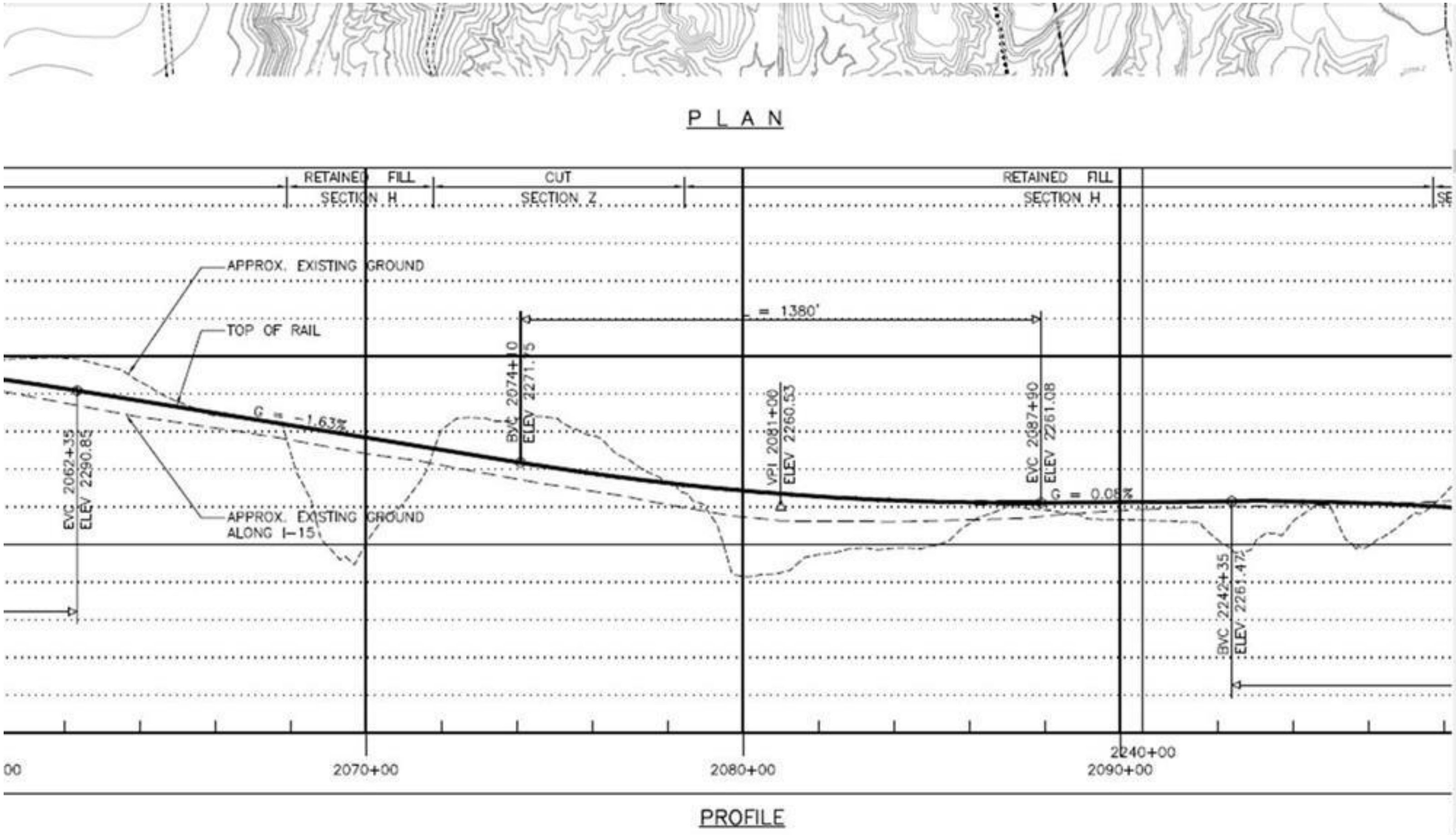
$Y = a + bx + cx^2$

where Y= the elevation of the vertical curve at a distance x feet from the VPC

a = the elevation of VPC (feet)

b = the slope of the entering tangent (ft/ft) $= G_1$

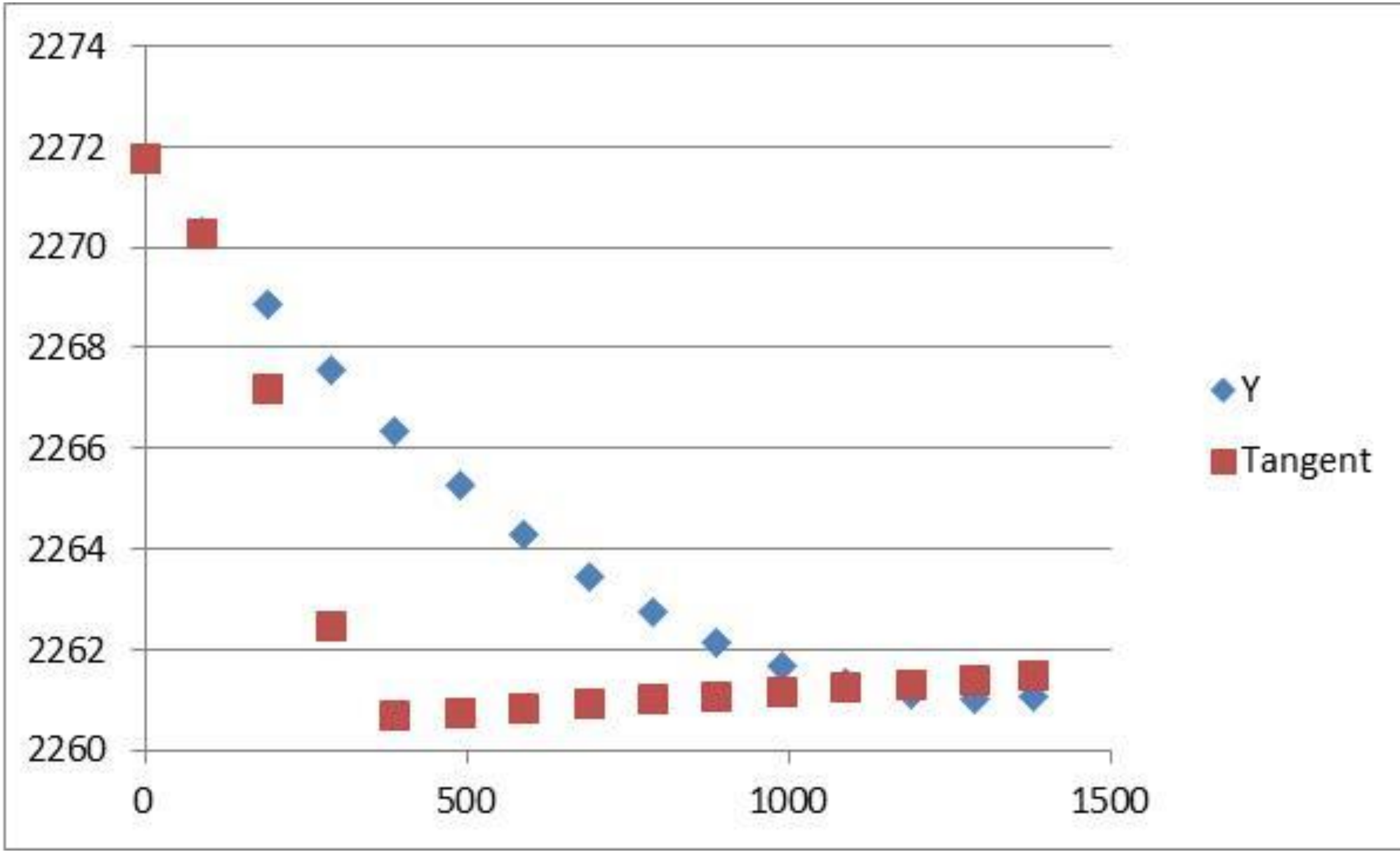
c = the rate of change in grade


PLAN
RETAINED FILL
SECTION H
CUT
SECTION Z
RETAINED FILL
SECTION H
APPROX. EXISTING GROUND
TOP OF RAIL
= 1380'
G = -1.63%
G = 0.08%
EVC 2062+35
ELEV 2290.85
BVC 2074+10
VPI 2081+00
ELEV 2260.53
EVC 2087+90
ELEV 2261.08
APPROX. EXISTING GROUND
ALONG I-15
BVC 2242+35
ELEV 2261.47
2070+00
2080+00
2240+00
2090+00
PROFILE

G1=	-0.0163
G2=	0.0008
A=	0.6
D=	0.0171
K=	2.15
L=	1,380
V=	150
L=	1,379

a=	2271.75
b=	-0.0163
c=	6.19565E-06
A=	0.0171
L=	1,380

			x	x	x	Y
BLEV	2271.75		207410		0	2271.75
			207500	90	90	2270
			207600	100	190	2269
			207700	100	290	2268
			207800	100	390	2266
			207900	100	490	2265
			208000	100	590	2264
			208100	100	690	2263
			208200	100	790	2263
			208300	100	890	2262
			208400	100	990	2262
			208500	100	1090	2261
			208600	100	1190	2261
			208700	100	1290	2261
ELEV	2261.47		208790	90	1380	2261



2274
2272
2270
2268
2266
2264
2262
2260
0
500
1000
1500
Y
Tangent

HSR vertical curve

- The recommended minimum length of the vertical curve = 100 feet.
- The minimum distance between vertical curves shall not be less than 100 feet.
- When making curve length computations, vertical curve lengths are typically rounded up to the next 50 or 100 feet.
- **North American vertical curves are parabolic** while European curves are designed as a function of the radius.

- It is recommended that the designer compare the calculated vertical curve against criteria developed and used in other international high speed system

European Design of Vertical Curve

- A vertical curve is provided if when the two grandients is greater than 2‰

$R_{\text{equivalent vertical radius}} = \rho_{\text{equiv}} = V^2 / 2$

$R_{\text{extreme radius}} = \rho_{\text{ext}} = V^2 / 4$

$R_{\text{minimum acceptance in Europe}} = \rho_{\text{min}} = 2000$ m (6,567 ft.)

Where; V is in $(\text{km/h})^2$

R is in meters (m)

The radius of the vertical curve can be worked out based on the following relationship between speed of the vehicles, radius of the vertical curve and permissible values of vertical accelerations.

$R_v \geq V^2{}_m/a_m$

Where, R_v = Radius of vertical curve in meter

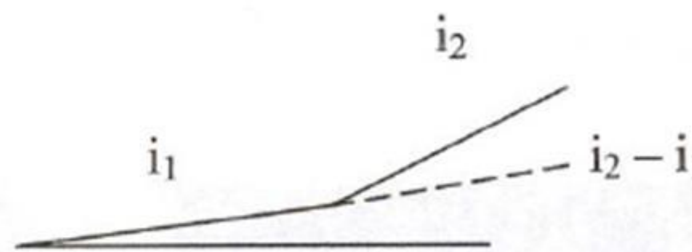
V_m = maximum permissible speed of the vehicle in m/sec

a_m = permissible vertical acceleration in m/sec^2

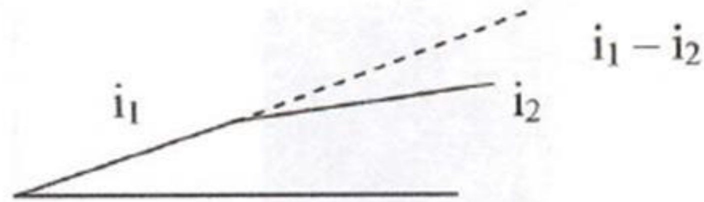
European Design of Vertical Curve (cont.)

$T = \rho/2 * (i_2) / 1000$ $i_1 = 0$ ‰

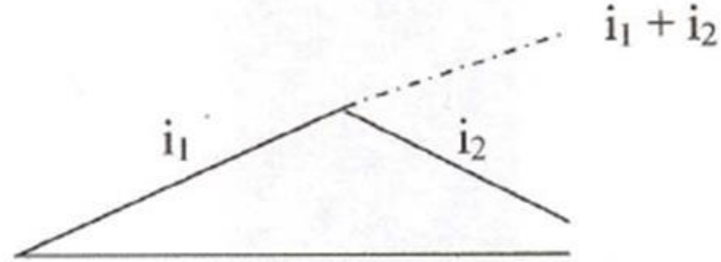
$T = \rho/2 * (i_2 - i_1) / 1000$ (sag curve)



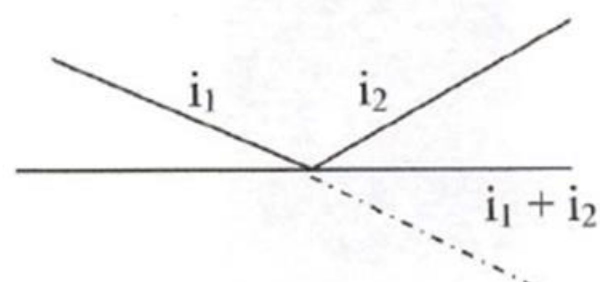
European Design of Vertical Curve (cont.)



$T = \rho/2 * (i_1 - i_2) / 1000$ (crest curve)



$T = \rho/2 * (i_1 + i_2) / 1000$ (crest curve)



$T = \rho/2 * (i_1 + i_2) / 1000$ (sag curve)

Sweden Vertical Curve Design

$R_{v\,min} \geq 0.16 * V^2$

V = *permissible speed in km/h*

R_v = *Vertical curve radius in m (multiply by 3.28083 to convert to feet)*

The recommended vertical curve radius is derived as follows:

$R_{v\,rec\,min} \geq 0.25 * (1.3 * V^2)$

Where 1.3 is a speed factor applied with respect to ride comfort and future increased speed.

For tilt equipment, the minimum vertical curve radius is calculated using an overspeed of 25%

$R_{v\,min\,tilt} \geq 0.25 * V^2$

Vertical Curve Design in Germany

V = *permissible speed in km/h*

R_v = *Vertical curve radius in m (multiply by 3.28083 to convert to feet)*

$R_{v\ rec\ min} \geq 0.40 * V^2$ *(Recommended minimum value)*

$R_{v\ limit} \geq 0.25 * V^2$ *(Limit value)*

$R_{v\ crest} \geq 0.16 * V^2$ *(Vertical curve radius on a crest permission required)*

$R_{v\ sag} \geq 0.13 * V^2$ *(Vertical curve radius in a hallow or sag permission required)*

$R_{v\ abs\ min} \geq 2{,}000$ m *(Absolute minimum vertical curve radius permission required)*

Table 17-3-2. Recommended Minimum Value for Vertical Curve Radius at 200 km/h

Vertical Curve Radius	200 km/h (approx. 125 mph)
Recommended minimum	16,000 m (52,493 feet)
Limit	10,000 m (32,808 feet)
Permission value on a crest	6,400 m (20,997 feet)
Permission value in a hallow or sag	5,200 m (17,060 feet)

Vertical Curve Design in Taiwan

- Vertical curve Va<0.20 m/s

Vertical Curve Radius	
Recommended minimum	19,000 m (62,336) at 200 km/h (approx. 125 mph)
Limit	25,000 m (82,020) at 350 km/h (approx. 217 mph)

Vertical Curve Design in Japan

	Tokaido Shinkansen	**Sango Shinkansen**	**Tohoku-Joetsu Shinkansen**
Maximum gradient, ‰	20 ‰ (2%)	15 ‰ (1.5%)	15 ‰ (1.5%)
Minimum Vertical Curve Radius, m	10,000 m (32,808 feet)	15,000 m (49,212 feet)	15,000 m (49,212 feet)

Technical Specifications of Interoperability (TSI)

$R_v = V^2_{max} / 12.96 * a_v \geq R_{v,\ limit\ value}$

V = permissible speed in km/h

R_v = *Vertical curve radius in m (multiply by 3.28083 to convert to feet)*

a_v = *vertical acceleration taking into consideration ride comfort where ther*
(m/s^2).

Limiting Values of Vertical Acceleration, av

Table 17-3-3. Traffic Categories, Limiting Values of Vertical Acceleration, a_v

Vertical Acceleration	Mixed traffic lines designed for passenger trains $200 < V \leq 300$ (km/h)	Mixed traffic lines with passenger trains $V \leq 230$ (km/h)	High-speed lines with dedicated passenger traffic $200 < V \leq 300$ (km/h)
Recommended limiting values (m/s^2)	0.22	0.22	0.22
Maximum limiting values (m/s^2)	0.44	0.31	0.44

Limiting Values of Vertical Curve Radius, Rv

Table 17-3-4. Traffic Categories, Limiting Values of Vertical Curve Radius, R_v

Vertical Curve Radius	Mixed traffic lines designed for passenger trains $200 < V \leq 300$ (km/h)	Mixed traffic lines with passenger trains $V \leq 230$ (km/h)	High-speed lines with dedicated passenger traffic $200 < V \leq 300$ (km/h)
Recommended limiting values (m)	$0.35\ V^2$ *max*	$0.35\ V^2$ *max*	$0.35\ V^2$ *max*
Maximum limiting values (m)	$0.175\ V^2$ *max*	$0.25\ V^2$ *max*	$0.175\ V^2$ *max*

Limiting Values on Vertical Curve Radius (sample at 200 km/h)

Table 17-3-5. Example - Limiting Values on Vertical Curve Radius (sample at 200 km/h)

Speed (km/h)	200 km/h (125 mph) Vertical Curve Radius (m)
Recommended Value	14,100 m (46,260 feet)
Minimum value without tolerance	7,100 m (23,294 feet)
Minimum value on a crest	6,400 m (20,998 feet)
Minimum value in a hallow or sag	5,400 m (17,717 feet)

Practical Design of Profiles

- For the design of main lines, it is typical to use the flattest (lowest gradient) profile that the topography and other physical and operational constraints will permit, regardless of the intended operating speed.
- The maximum speeds desired will dictate the minimum lengths of vertical curves and conversely, if the desired profile cannot be used, the lengths of vertical curves will limit maximum speeds.
- Wherever, possible, the longest vertical curve should be used for future expansion.
- In areas where there is a shared corridor (high speed rail and freight), the reader should refer to AREMA

Other Considerations

- Turnouts, station platforms, bridges, and at-grade road crossings should not be placed in vertical curves.
- It is desirable to avoid placing vertical curves within the limits of horizontal curves.
- Undulating profiles consisting of many short vertical curves and tangents should be avoided.
- It is generally considered poor practice to design an erratic profile for the purposes of balancing earthwork or to “hit” a series of existing elevations along the track.
- Vertical clearance to overpasses and other overhead structures must be considered. Future electrification may have to be considered. It is recommended to allow 0.5 to 1.0 foot additional clearance to account for future track maintenance.

Geometric Design

-- Gradient and turnout

Factors determining **gradients**

- Power supply and energy consumption which increase with large gradients
- Some freight trains with friction-based traction locomotive power may have problem ascending and/or descending the gradients
- Braking distances increase in descending gradients
- Maximum speed achieved and/or permitted
- Train handling issues
- Ride quality
- Climate effects which reduce adhesion

Freight operation in North America

- A 1% maximum gradient is typically preferred
- Grades of 2% and slightly more are fairly common on many existing lines
- Consider the overall territory and not to add a steep grade so as to change the operational characteristics of the line

Freight operation in North America (cont.)

- Commuter or passenger service where trains are typically operated at greater horsepower per ton ratios than freight trains, the impact of gradients are considerably less
- On lines with mixed traffic, gradients and curves must be selected that support the desired operation of all vehicle and trains types

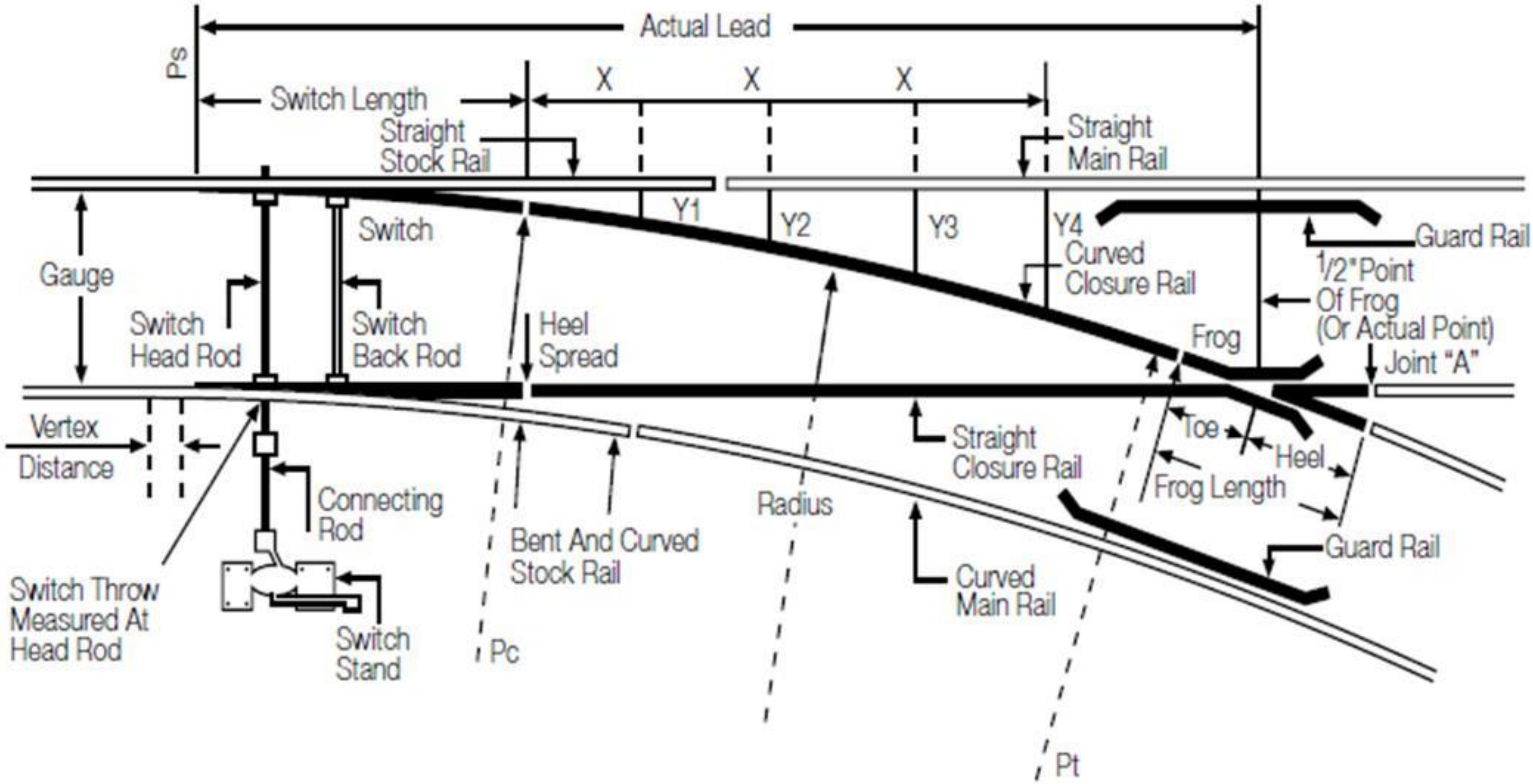
General guidelines

- 0% to 1.0% - generally considered acceptable for freight and passenger service
- 1.1% to 2.0% - acceptable for combined passenger and freight service if they are in compliance with maximum grades elsewhere on the line
- 2.1% to 3.0% - may be acceptable in passenger service and short ancillary freight service
- 3.1% to 4.0 – may be acceptable in passenger service, preferably only for short distances such as flyovers
- Grades above 4% are not recommended
- 0% to 0.2 % - preferred for maintenance and layover facilities

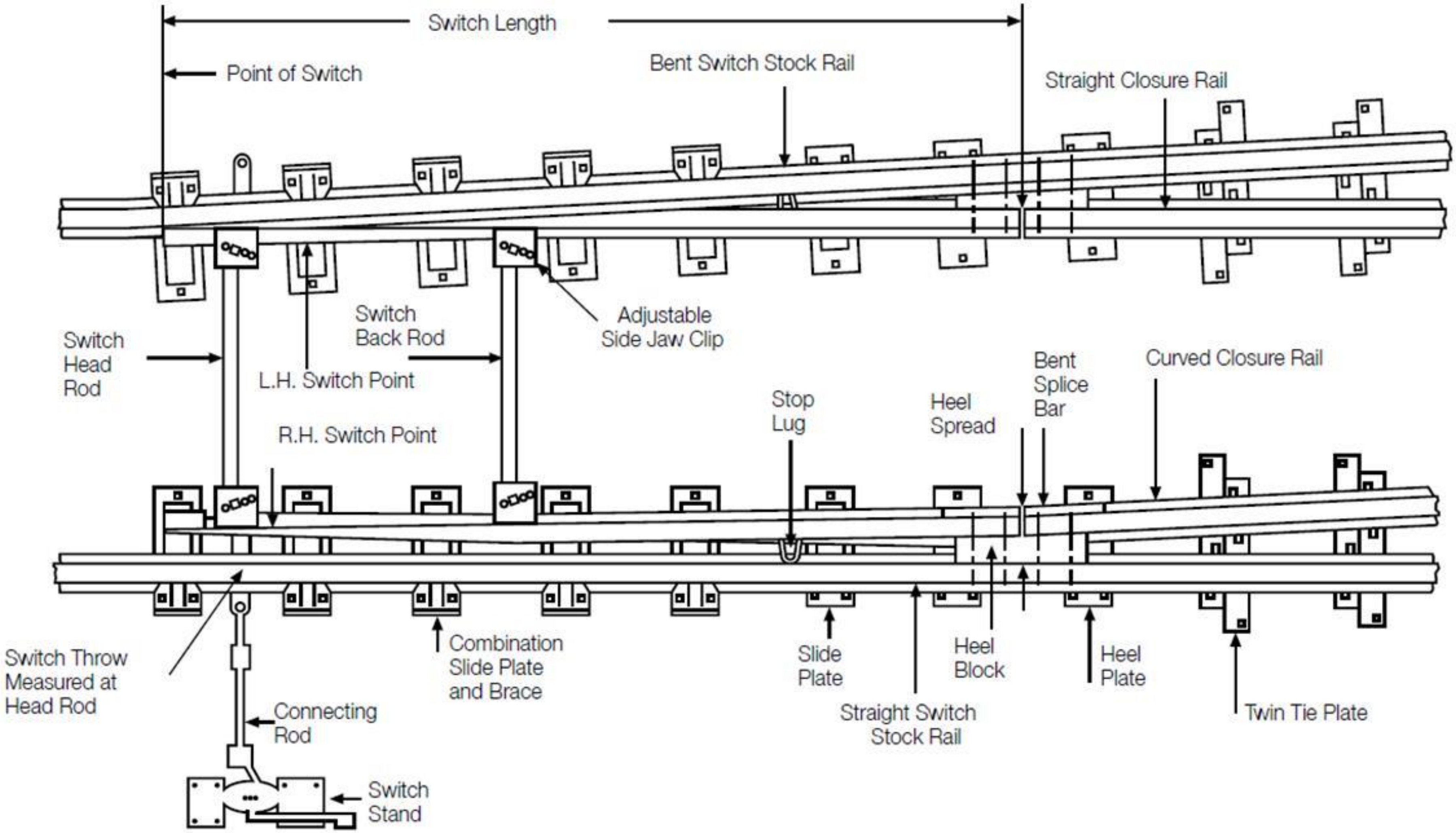
Compensated gradient

- A train on a grade that is on a horizontal tangent will encounter even greater resistance when moving into a horizontal curve
- To keep train resistance more uniform, the gradient can be slightly reduced in the horizontal curve to account for increased resistance of the horizontal curve
- Grade compensation should be considered in the areas of mixed traffic

Turnouts



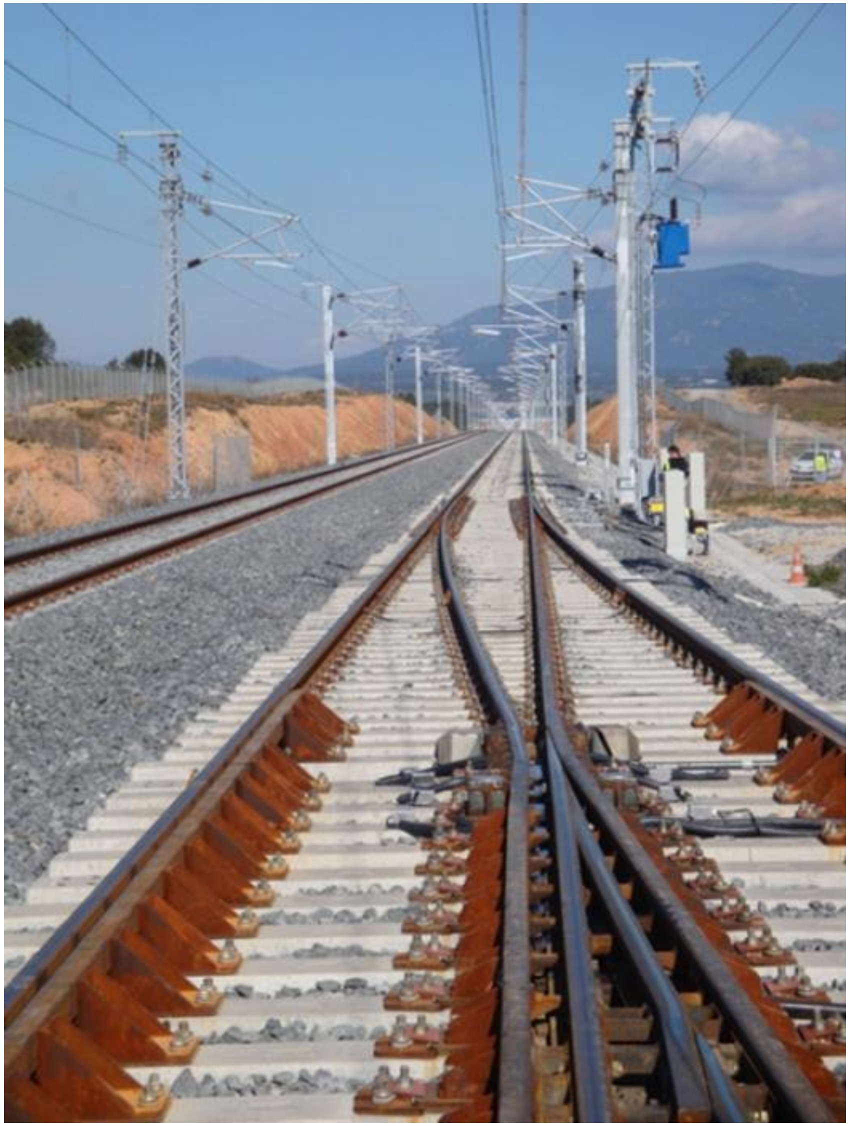
Actual Lead
Ps
Switch Length
X
X
X
Straight Stock Rail
Straight Main Rail
Y1
Y2
Y3
Y4
Switch
Guard Rail
Curved Closure Rail
Gauge
1/2" Point Of Frog (Or Actual Point)
Switch Head Rod
Switch Back Rod
Heel Spread
Frog
Joint "A"
Vertex Distance
Toe
Heel
Straight Closure Rail
Frog Length
Connecting Rod
Radius
Bent And Curved Stock Rail
Guard Rail
Curved Main Rail
Switch Throw Measured At Head Rod
Switch Stand
Pc
Pt



Switch Length
Point of Switch
Bent Switch Stock Rail
Straight Closure Rail
Switch Head Rod
Switch Back Rod
L.H. Switch Point
Adjustable Side Jaw Clip
R.H. Switch Point
Stop Lug
Heel Spread
Bent Splice Bar
Curved Closure Rail
Switch Throw Measured at Head Rod
Connecting Rod
Switch Stand
Combination Slide Plate and Brace
Slide Plate
Straight Switch Stock Rail
Heel Block
Heel Plate
Twin Tie Plate

Product

- Rail
- Switch rail
- Frog
- Guard rail
- Rail joints and joint bars
- Switch and frog plates and fasteners
- Switch and frog connections
- Switch ties



Clamp Lock (VCC)
It is an individual locking and switch rail control device. Both switch rails are locked and individually controlled in their final positions.

Swing nose clamp lock (VPM)
It locks the swing nose and is fixed to the cradle, working on the same principle as the VCC.

Paulvé detector,
It controls the application and opening of switch rails

- www.vossloh-cogifer.com/media/downloads/.../BrochureVspeed-EN.pdf

▶ Ballasted track

▶ Slab track

▶ Integrated hydraulic drive

▶ Multiple drive system

▶ Integrated mechanical drive

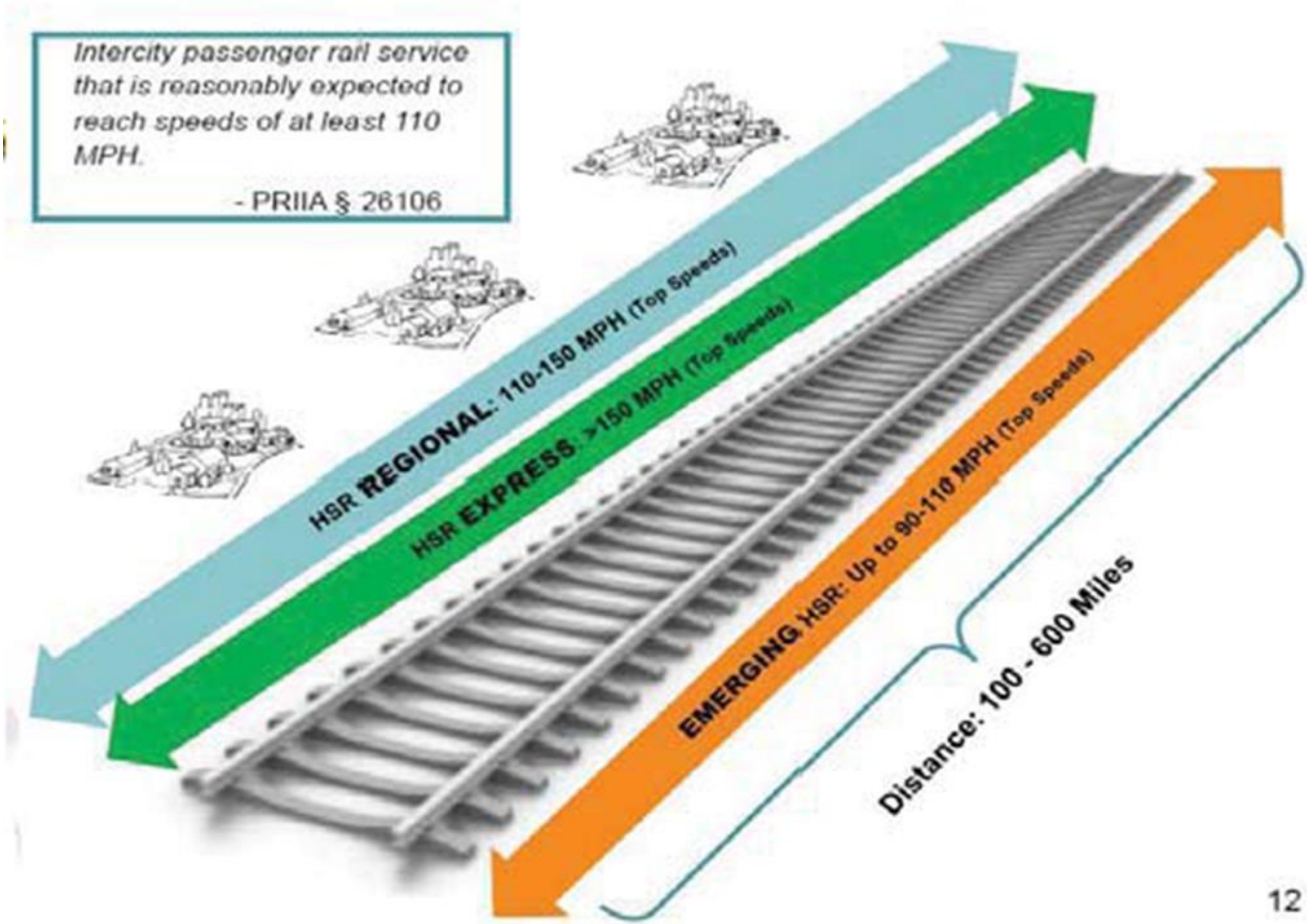
▶ Single drive system

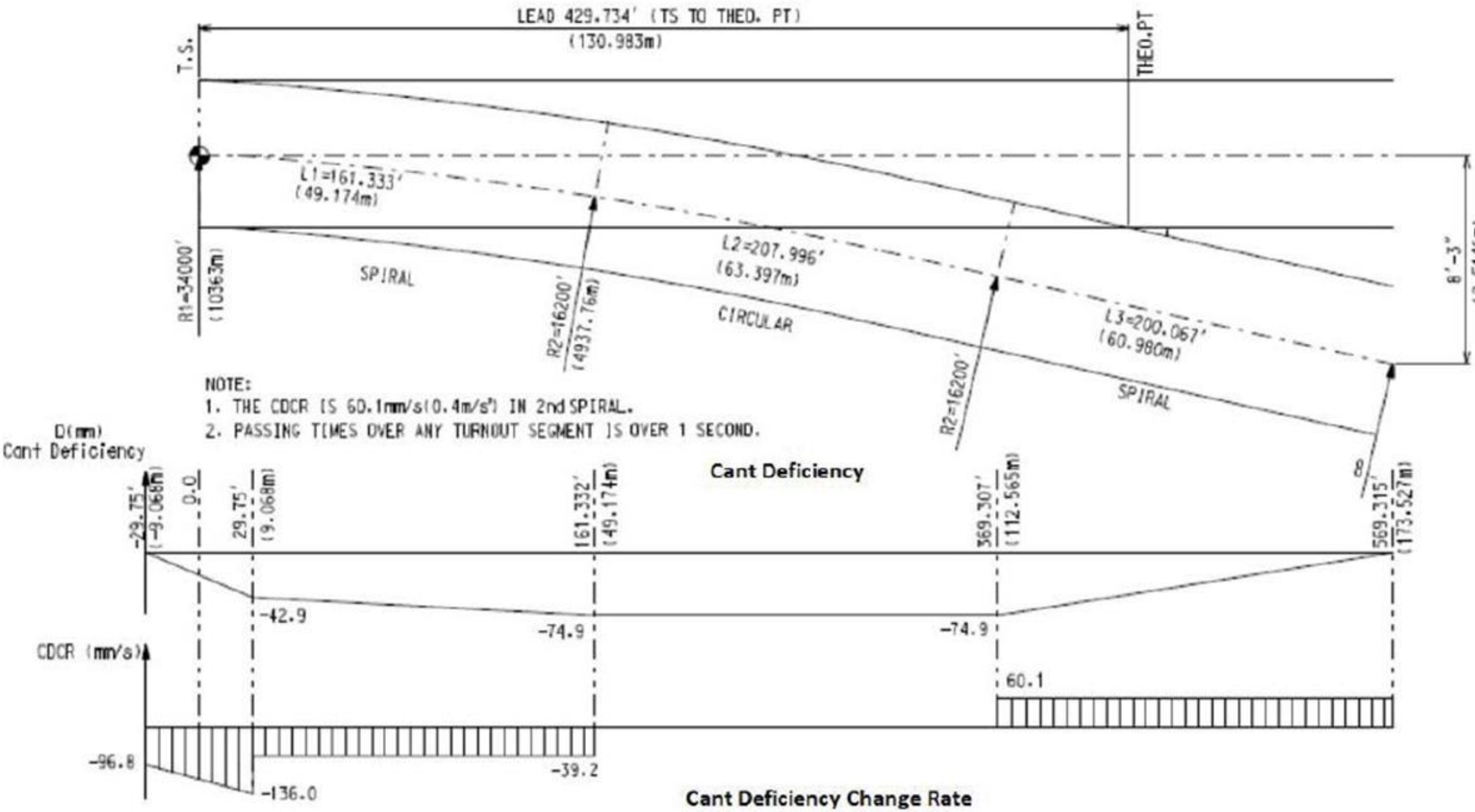
AREMA recommendations for Rail ….

- Stock rail, closure rail and other turnout rails for high speed turnout should be new, fully heat treated or head hardened rail.
- Rails should be produced with a minimum Brinell Hardness Number (BHN) of 350 and a maximum as recommended by AREMA for premium rail
- Stock rail should be fabricated in compliance with AREMA recommendation
- Neither a joint or a weld lies on a tie nor within 3 in of the face of any tie
- Raised brands should be ground flush at joint bar locations
- Thermal restraint insert should not be used in the base of rail

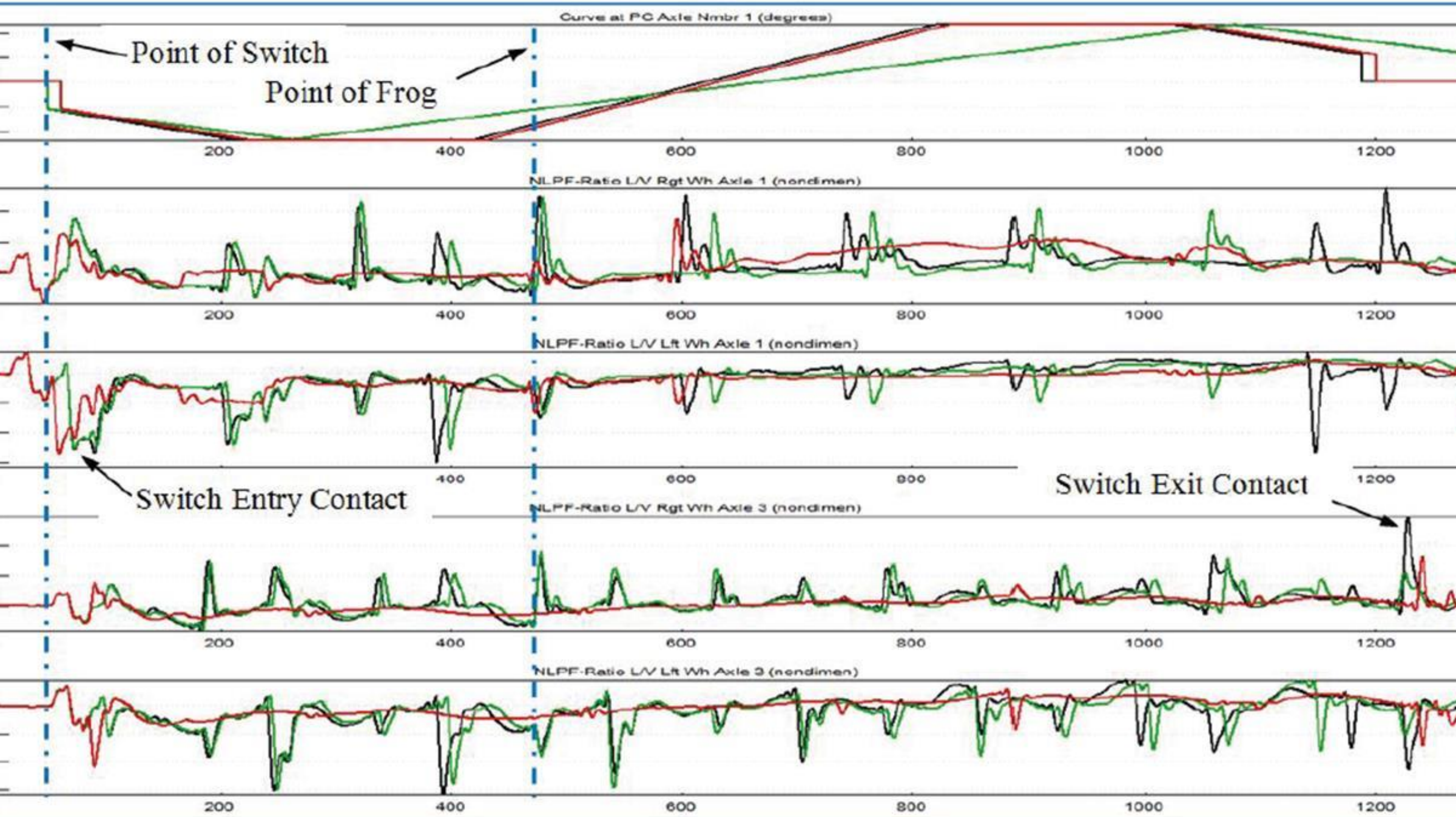
Passenger comfort

- Lateral acceleration: 0.04-0.08
- Wheel impact

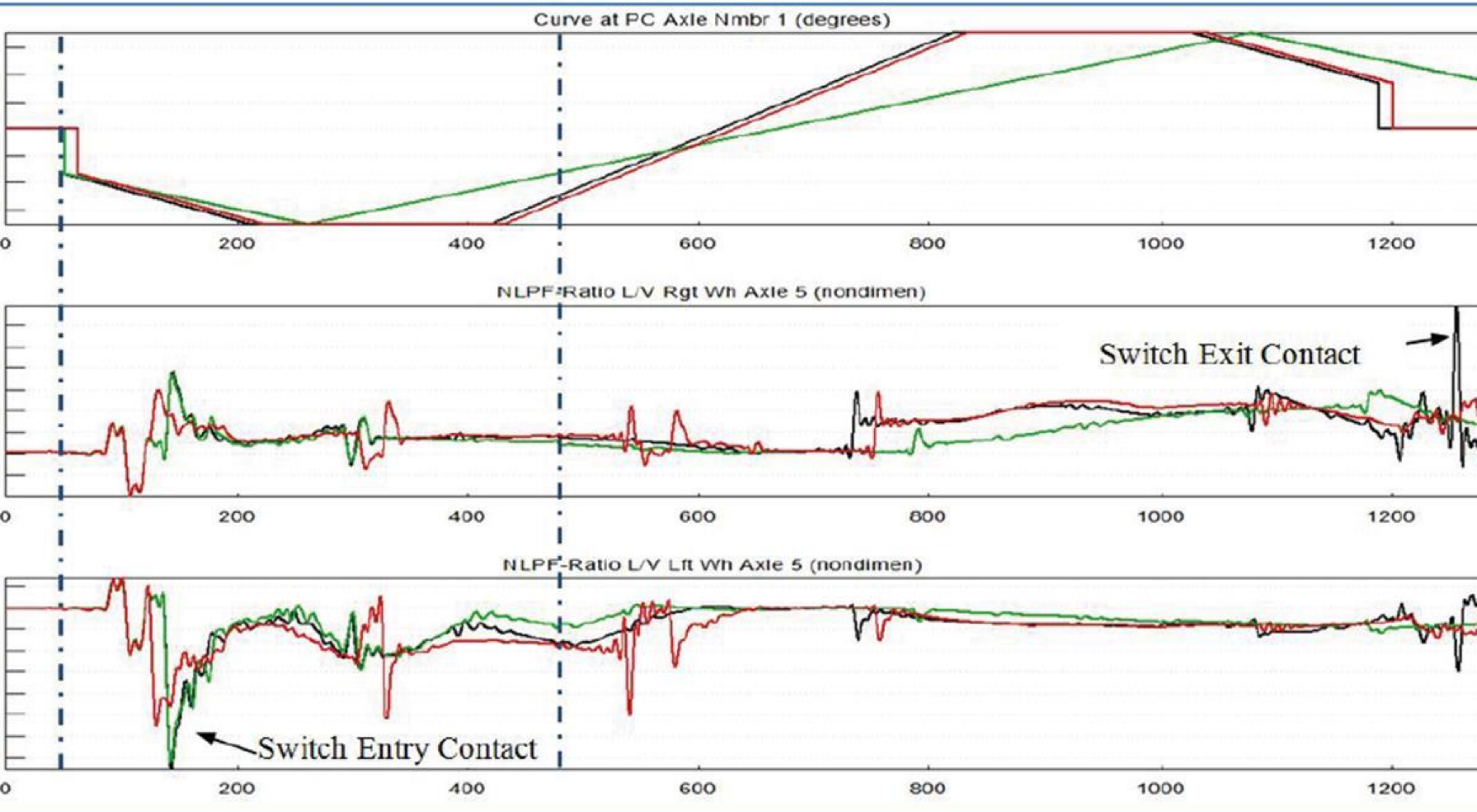

Intercity passenger rail service that is reasonably expected to reach speeds of at least 110 MPH.
- PRIIA § 26106
HSR REGIONAL: 110-150 MPH (Top Speeds)
HSR EXPRESS: >150 MPH (Top Speeds)
EMERGING HSR: Up to 90-110 MPH (Top Speeds)
Distance: 100 - 600 Miles



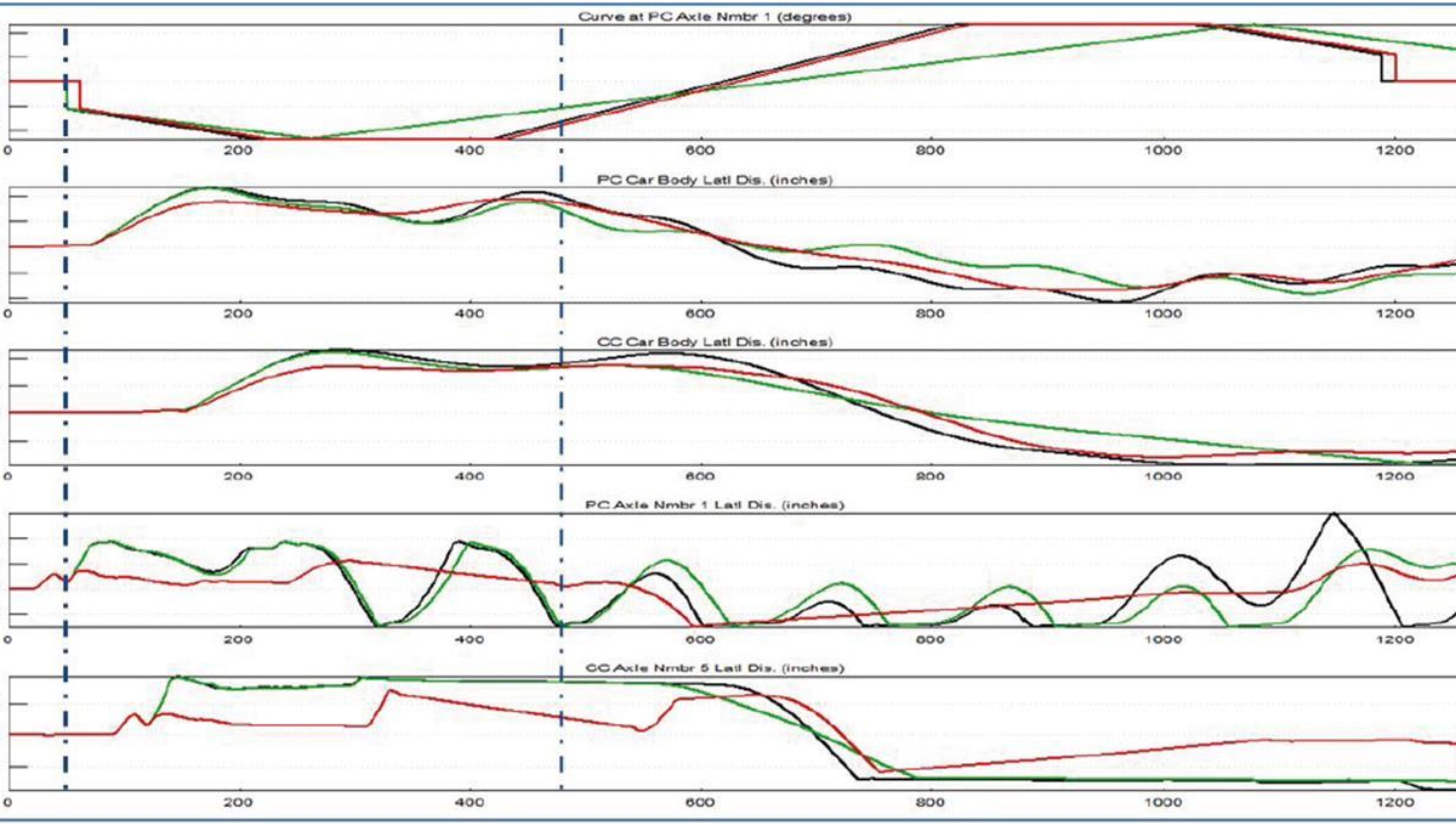
LEAD 429.734' (TS TO THEO. PT)
(130.983m)
T.S.
THEO.PT
L1=161.333'
(49.174m)
L2=207.996'
(63.397m)
L3=200.067'
(60.980m)
R1=34000'
(10363m)
SPIRAL
R2=16200'
(4937.76m)
CIRCULAR
R2=16200'
SPIRAL
8'-3"
(2.5146m)
NOTE:
1. THE CDCR IS 60.1mm/s(0.4m/s²) IN 2nd SPIRAL.
2. PASSING TIMES OVER ANY TURNOUT SEGMENT IS OVER 1 SECOND.
D(mm)
Cant Deficiency
Cant Deficiency
-29.75'
(-9.068m)
0.0
29.75'
(9.068m)
161.332'
(49.174m)
369.307'
(112.565m)
569.315'
(173.527m)
-42.9
-74.9
-74.9
CDCR (mm/s)
60.1
-96.8
-39.2
-136.0
Cant Deficiency Change Rate



ure 3. Power Car Wheel L/V Ratio Time Histories, APTA 240 Wheel, Slab Track, erging Line Crossover, 120 mph (Black Line: S-C-S, Green Line: S-S, Red Line: steer S-C-S)



ure 5. Coach Car Wheel L/V Ratio Time Histories, APTA 240 Wheel, Slab Track, erging Line Crossover, 120 mph (Black Line: S-C-S, Green Line: S-S, Red Line: steer S-C-S)



ure 6. Carbody and Axle Lateral Displacement Time Histories, APTA 240 Wheel, Slab ack, Diverging Line Crossover, 120 mph (Black Line: S-C-S, Green Line: S-S, Red Line: steer S-C-S)

High Speed Rail Aerial Structures

Outline

- TGV: Train a Grande Vitesse (France and Beigium)
- AVE: Alta Velocidad Espanola
- THSR: Taiwan High Speed Rail
- California HSR

- TGV: Train a Grande Vitesse (France and Belgium)

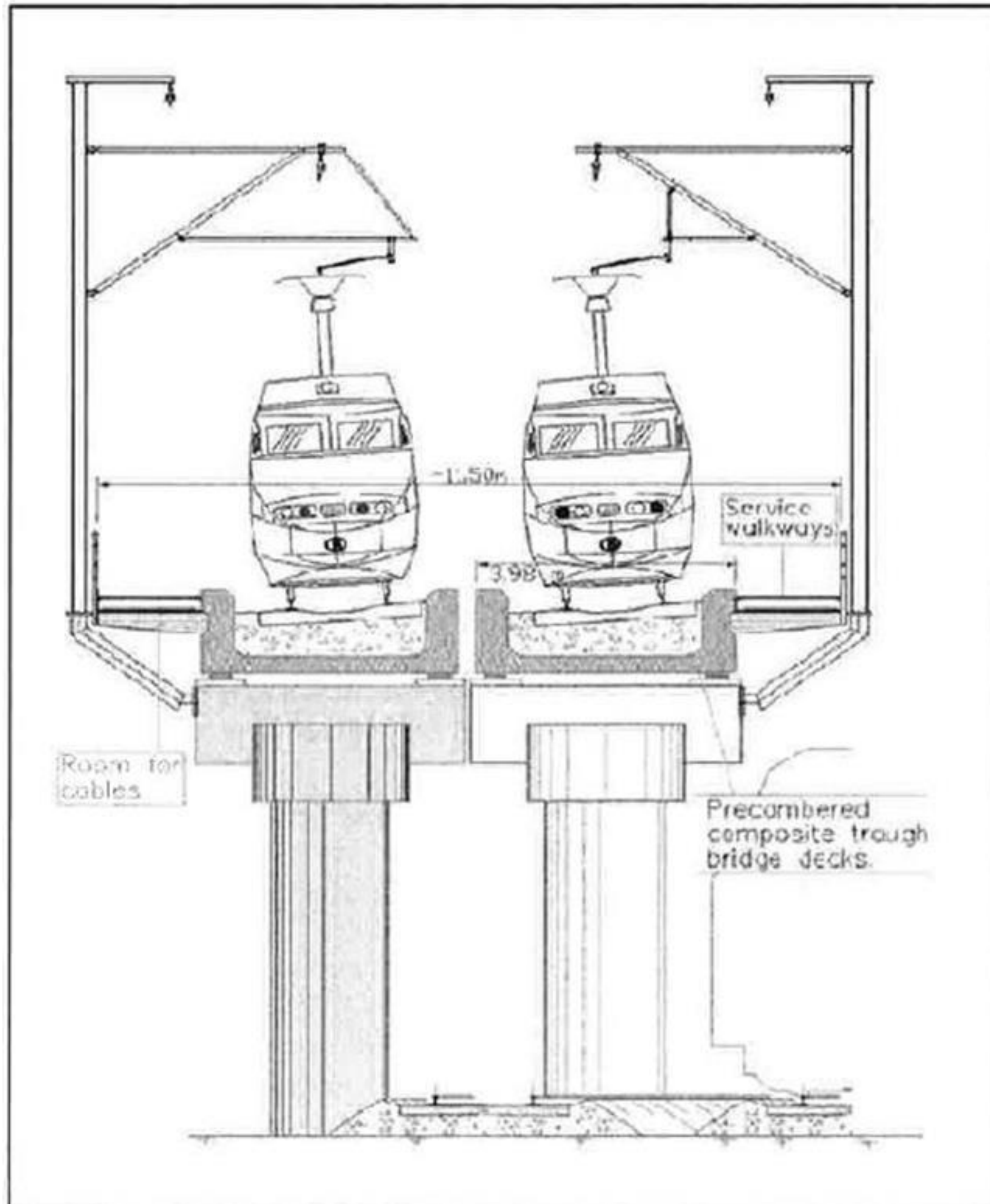


Figure 3-1: Deck Section for TGV in Belgium

Figure 3-2: TGV High-Speed Railway Viaduct in Belgium

Source: http://www.rail-be.net/Accessoires/Webs_Files/TUC_LGV.htm

Figure 3-3: Cheval Blanc Viaduct, France

Figure 3-4: Mosel 3 Viaduct

TGV: Train a Grande Vitesse (cont.)

- Pros:
  - Noise and vibration is minimized due to use of ballast
  - Prefabrication allows for quick assembly and implementation
  - Independent structure may allow for rapid restoration of single track service following seismic events that damages a single guideway

TGV: Train a Grande Vitesse (cont.)

- Cons:
  - Potentially new construction technique in the U.S.
  - Superstructure limited to short span lengths
  - **Limited seismic performance** of superstructure
  - Designed for maximum speeds of 186 miles per hour
  - Design needs to accommodate the added weight of ballast
  - OCS poles located outside of walkway require stronger mast arms and supports

- AVE: Alta Velocidad Espanola (Spain)

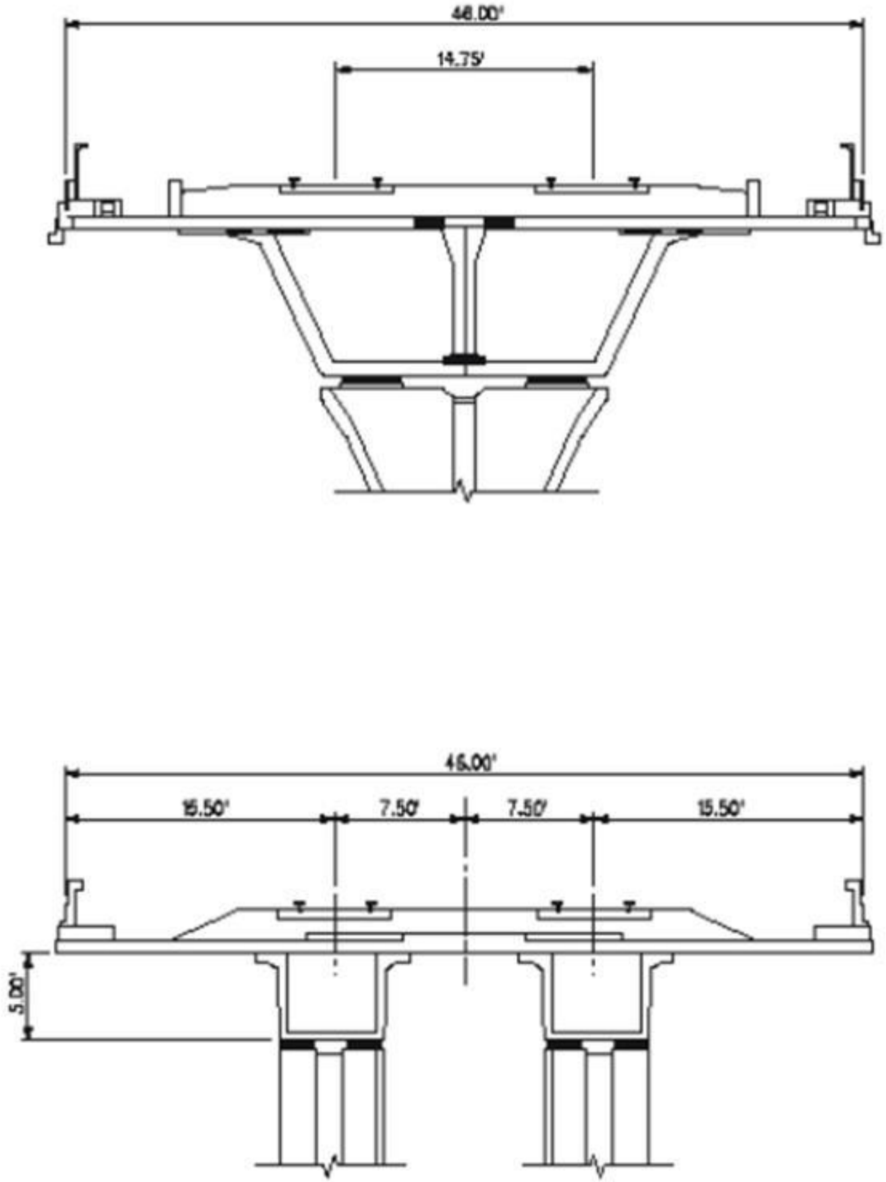


Figure 3-5: AVE Box Girder and Double Beam Cross Section
(Courtesy of PRAINSA)

Figure 3-6: AVE High Speed Rail Viaduct

AVE: Alta Velocidad Espanola (cont.)

- Pros:
  - Precast concrete box bridges allows for quick assembly and implementation
  - Designed for speeds up to 220 mph
  - Open box girder allows access for maintenance and inspection
  - Larger spans between pier – 80 to 200 feet (25 to 60 meters)

AVE: Alta Velocidad Espanola (cont.)

- Cons:
  - Two celled box girder restricts continuous maintenance access
  - Train loads not located directly over webs, instead loads are first carried by top slab and transferred to webs
  - Creating box girder to top of column moment continuity, if desired, is difficult requiring secondary closure pours and continuity tendons

THSR: Taiwan High Speed Rail

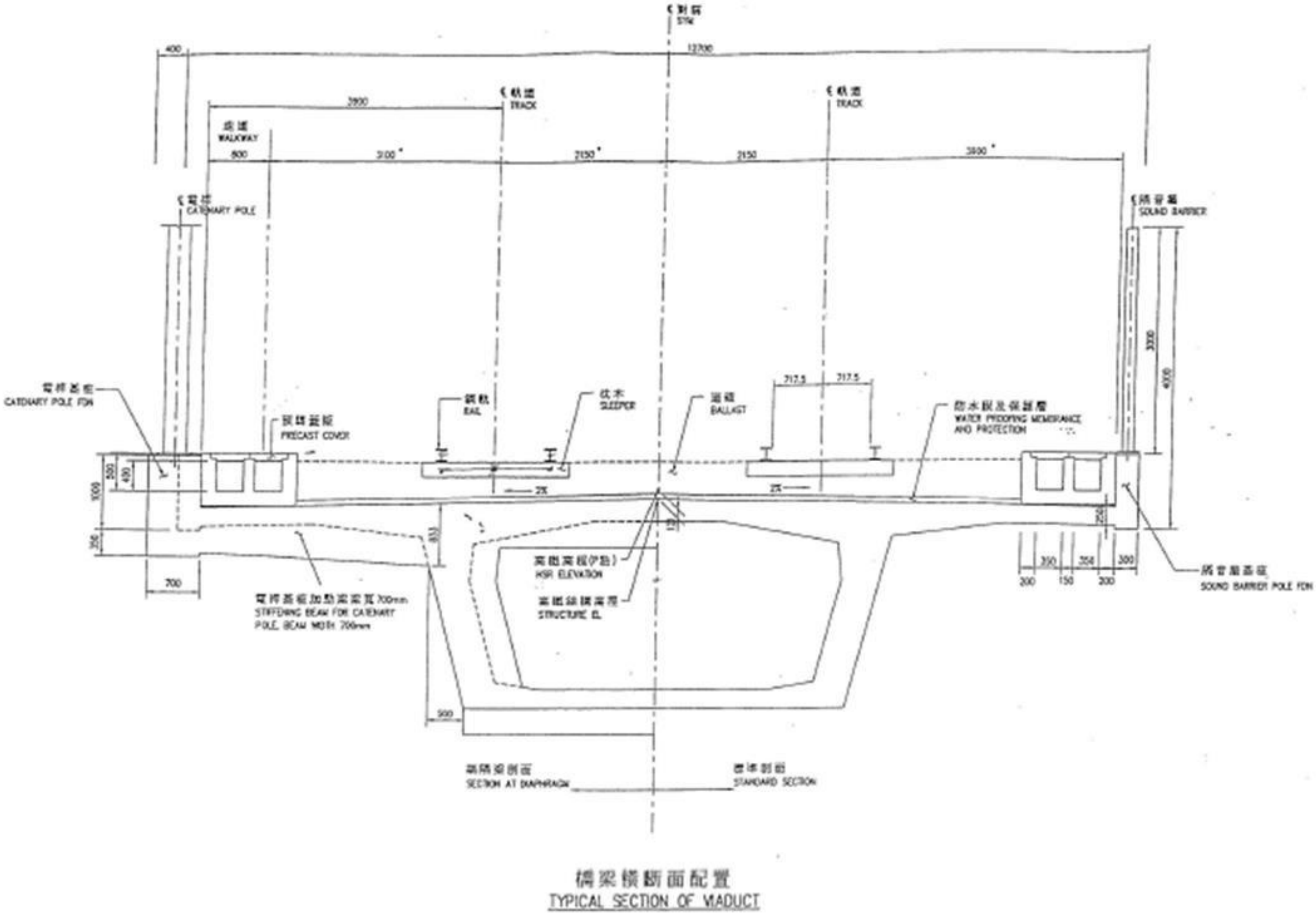


Figure 3-7: Section of Taiwan High-Speed Rail Viaduct

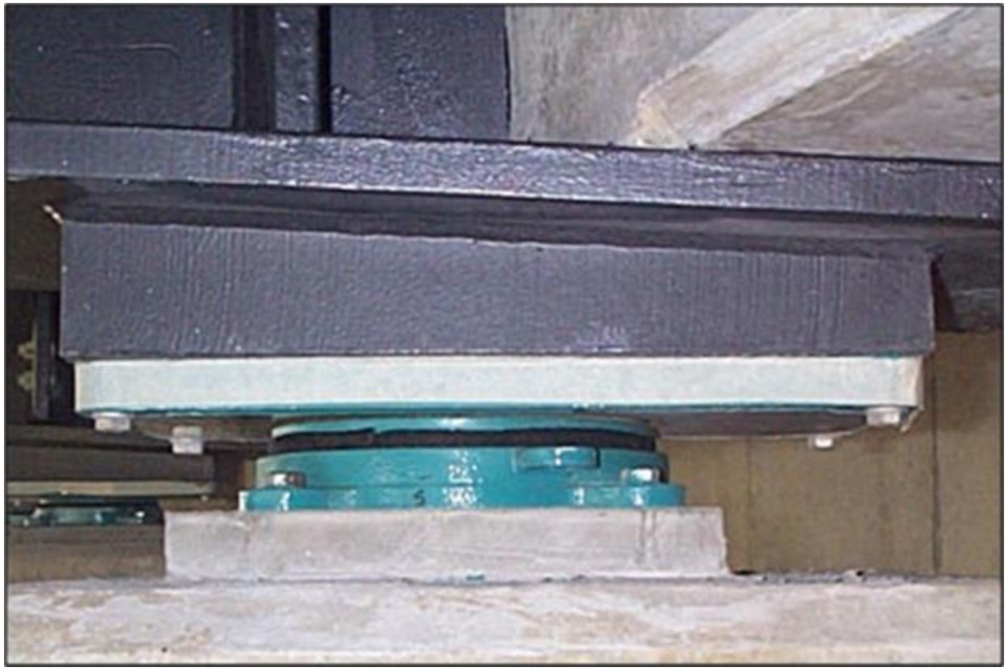
Figure 3-8: Taiwan High-Speed Rail Viaduct

Source: http://www.lusas.com/case/bridge/taiwan.html.

Source: http://www.lusas.com/case/bridge/taiwan.html

THSR: Taiwan High Speed Rail

- Pros:
  - Designed to withstand seismic events similar to those expected in California
  - The **shear key** spring, foundation and **bearing** spring have been used effectively with stiff connections to withstand similar seismic events as those expected in California.
  - Single box girder allows for ease of access
  - Distances between columns allow for transverse access below the guideway



http://www.steelconstruction.info/Bridge_articulation_and_bearing_specification

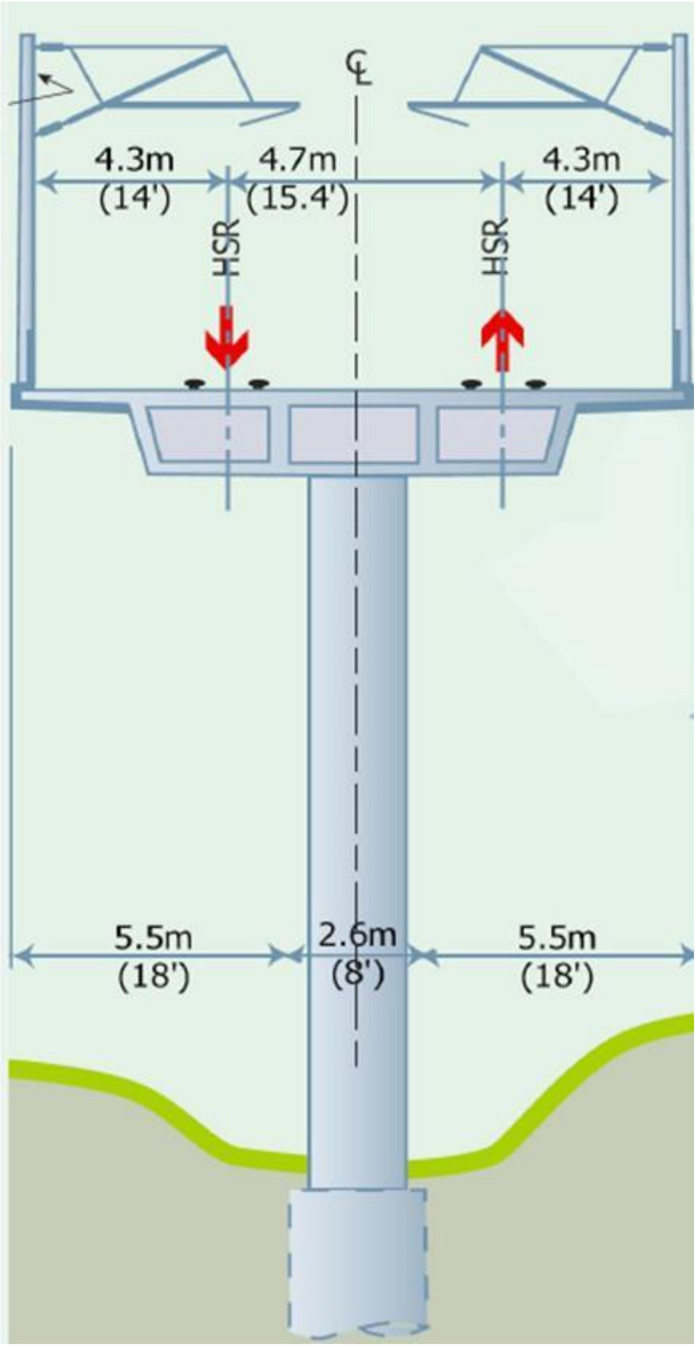
- Damage to shear key at intermediate support.
- https://www.researchgate.net/figure/269445386_fig9_Figure-9-Damage-to-shear-key-at-intermediate-support

THSR: Taiwan High Speed Rail (cont.)

- Cons:
  - OCS poles located outside walkway require stronger masts and supports
  - Open steel girders are difficult to maintain

California High Speed Rail Authority

- 100-foot-long typical span with a span to depth (S/D) ratio of 10
- The typical span could be longer (up to 130-foot-long) with a proportionally deeper cross section and thicker top deck, bottom soffit and web sections
- The cross section is also applicable to a direct fixation track structure



- Figure 3-9: Viaduct Section from California High-Speed Train Program EIR/S

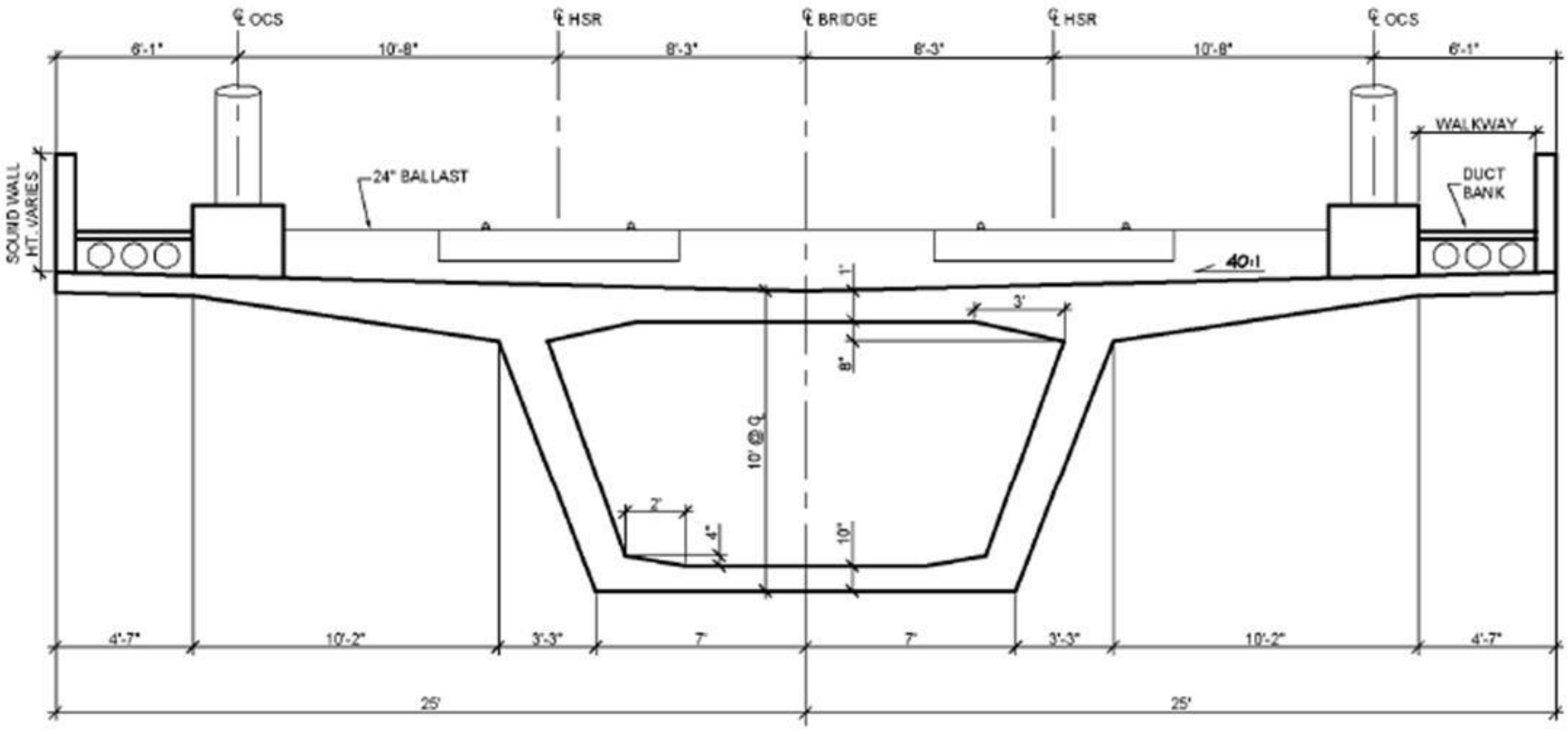


Figure 3-10: Basic High-Speed Train Aerial Structure Cross Section at Mid-span (100' span)

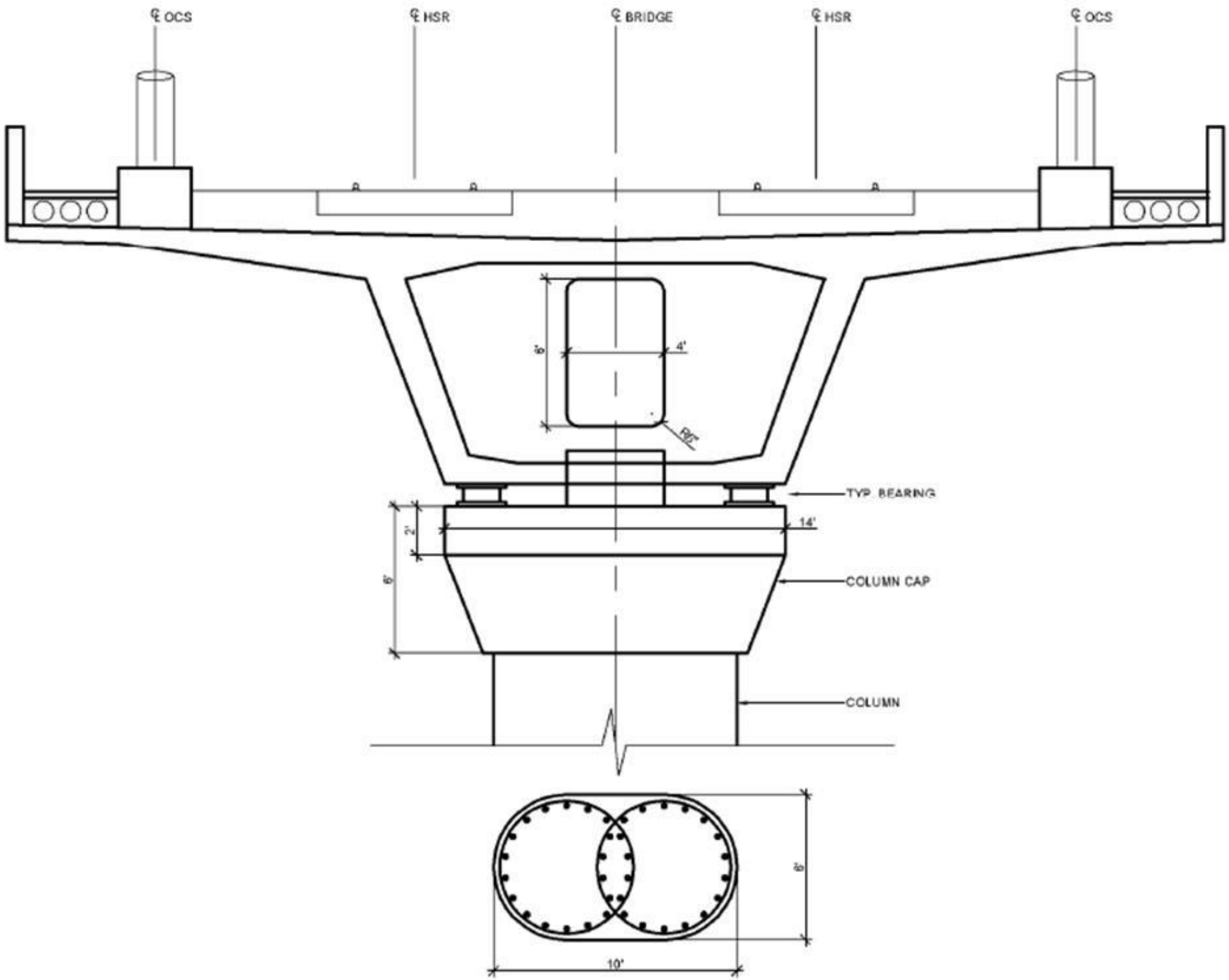


Figure 3-11: Basic High-Speed Train Aerial Structure @ Support

Table 1: Design Parameters for Basic High-Speed Train Aerial Structure

Structural Performance	
Design Life	100 years as defined in TM 1.1.2: Design Life
Design Criteria Compliance	Rigid and stiff structure needs to comply with stringent project specific design parameters, including seismic resistance, passenger comfort, and train performance criteria
Load-Bearing Capacity	Carries self weight, ballast, dynamic live loads of high-speed trains
Damage Resistance	Ductile seismic design philosophy based upon project seismic design criteria
Fatigue Resistance	Structural design and routine maintenance will address and monitor fatigue
Reparability	Inelastic action directed to base of columns during severe seismic event, where observable and readily repairable. Standard bearings and ancillary parts allow for inventory to facilitate quick replacement

Functionality	
Tracks	Allow for double main tracks to be carried on a single structure
Track Support	Allow for both direct fixation and ballasted track
Sound Walls	Accommodate low sound walls, where required, to mitigate sound from wheel on rail connection while not obstructing passenger views
Drainage	Drainage is collected away from the tracks and the duct banks through the girder and directed to discharge location at columns
Overhead Contact System (OCS)	Provided based on electrical current requirements
Traction Power Supply System	Mount multiple, large diameter conduits on columns and route onto the guideway
Lighting	Permanent maintenance lighting is not required to on aerial structures. Maintenance lighting will be provided as part of maintenance operations. Aerial structures are required to have lighting facilities for emergency access and egress
Walkways	Walkways are located outward of the OCS masts.
Railing/Parapet	Continuous railing or solid parapet is provided along outside of viaduct. May be solid parapet or open railing
Intermittent Access Stairs or ramps	Structurally independent; located to meet maintenance and operational requirements. Access control/detection is required at stair and ramp access locations
Maintenance Access	Structurally independent of high-speed train guideway. Access control/detection is required at maintenance access locations
Cable/Duct Banks	Provided on both sides, under walkways
Signal Heads	Space provided in the cross-section to accommodate panels

Safety	
Passenger Evacuation	Walkways located outward of OCS poles with provision for emergency access and egress
Intrusion Protection / Detection	Continuous intrusion protection not required due to vertical separation. Fencing and detection systems to be installed where required
Serviceability	
Allowance for Regular Inspections, Maintenance and Repairs	Access stairways, walkways, and, single cell concrete girder provided for inspection.
Economy	
Materials & Structure Type	Pre-stressed concrete box girders
Economy of Scale	Schedule efficiency and cost economy are based upon precast segmental production or cast in place production with reusable traveling shoring
Manufacturing and Delivery	Precasting segments, transporting and erecting the segments to be further investigated
On-Site Storage	Storage sites for segments to be determined

Trackside Environment	
Ground Plane	Elevated structure minimizes permanent disturbances to existing ground surface
Noise Mitigation	Low sound walls mitigate sound from wheel on rail connection
Vibration Mitigation	Ballast (or ballastless tracks with lining) mitigates vibration
Property Access	Elevated structure maintains transverse access beneath the guideway
Color	Natural concrete color or pigmented concrete
Texture	Smooth or textured surfaces
Complementary/Contrasting Details	Architectural treatments as appropriate
Visual and Shadow Impacts	Standard structure promotes system identity, dimensions of box girder to minimize permanent shadows

Material Type

- Concrete
  - The most cost effective
  - Predominant use in CA
  - Reduced maintenance needs vs. steel
  - Reinforced and prestressed concrete design and construction technology advanced, particular in earthquake prone California
  - High-strength concrete vs. stiffness
- Steel
  - Cost
  - Maintenance

Constructability

- Cast-in-Place construction
  - Traditionally
    - Require temporary shoring, falsework, additional clearance provision
    - Slow, large labor effort
  - Recent advances
    - Travelling
    - Self launching shoring techniques

Figure 3-12: Example of Travelling Shoring System

Source: http://www.ibtengineers.com/Taiwan-High-Speed-Rail.html

Source: http://www.ibtengineers.com/Taiwan-High-Speed-Rail.html

Cast-in-Place construction (cont.)

- Pros:
  - Can be cast monolithically with the columns, result in superior structural performance for train operation, passenger comfort, and seismic response
- Cons:
  - The schedule impacts are greater vs. precast construction due to required closure pours coupled with the falsework set up and removal operations

Precast construction

- Each precast segment could extend over the entire 100 to 130 foot span
- The segment construction may be performed remotely in a construction yard and transported to the site
- https://www.youtube.com/watch?v=q9VYrrE_IUE

Figure 3-13: Example of Overhead Gantry

Source: http://www.launching-gantry-operator.com

Source: http://www.launching-gantry-operator.com

Precast construction (cont.)

- Pros:
  - Fast method of construction for multi-span structures
  - The most cost effective
- Cons:
  - Segment lengths are short and requires more foundations and has a significant increase o the structure costs
  - Support bearings require routine maintenance and increase the life cycle costs
  - More challenging to meet the performance requirements (seismic, passenger comforts, etc.)

Span length and span to depth ratio

- 100 foot-long span, single cell box, the typical span length, popular in Taiwan
- Longer segments, weigh more, and difficult to transport in urban areas
- Longer segments, heavier, require fewer but significantly stouter foundations
- A longer span length may prove to be cost-effective if the project site is easy access and transportation dist is short
- Span to depth ratio: 10, i.e., 10 feet depth

Span articulation

- Continuous span system
  - Pros
    - Stiff, particularly vertically
    - Provide moment continuity with the column top
    - **No bearings** and no potential for the spans to become **unseated** during strong motion seismic events
    - Maintenance associated with the bearings is eliminated
  - Cons
    - Using a precast construction method and providing span to **column top continuity** complicates the construction process
    - Lengthens the construction cycle, and
    - Potentially more costly
    - Stress analysis is more complicated

The construction of the substructure

- Substructure: piles, pile caps, spread footings, columns and column caps
- Occurs separately and before the erection of the precast segmental superstructure
- Constructed by traditional pour-in-place concrete methods
- Typical foundations are conventional spread footing
- With marginal soils
  - Pile cap with cast-in-drilled-hole (CIDH) or cast-in-steel-shell (CISS) piles

The construction of the substructure (cont.)

- Columns
  - Constant cross section
  - Cross section increasing in area from bottom to top
  - Architectural concrete flares and treatments
  - Have a reinforced structural core with vertical, shear, and confinement reinforcement

Track Structure

Truck components

- Track type
- Rail
- Ballastless track
- Clip
- Tie
- Ballast
- Turnout
- Weld
- Smoothness management

Track type

- Ballast
- ballastless

Ballast Track

- Pro:
  - Construction cost low
  - Sound noise not far
  - Short time to construct
  - Quick to reconstruct
  - More automatic and mechanical maintenance
  - Geometry easy to fix
- Con:
  - Tend to settlement, track structure deteriorate fast, damage geometric features
  - Aerodynamic cause ballast flies

Ballast Track (cont.)

- No difference from the conventional ballast in structure
- High quality structural components and maintenance standard
- Heavier components
  - Reduce load at the bottom of tie: heavy and wide ties
  - Increase longitudinal continuous support: wide ties,
  - Increase rail elasticity: use plastic

Ballastless track

- Pros:
  - High stability
  - Smooth
  - Endurable
  - Lower weight center
  - Light weight
  - Less construction for tunnel
  - Less load to bridge
  - Cleaning and good looking
  - No ballast flying
  - Track deformation slow
  - Less maintenance
- Cons:
  - Capital cost high
  - Stiffness high
  - Elastic low
  - High vibration noise

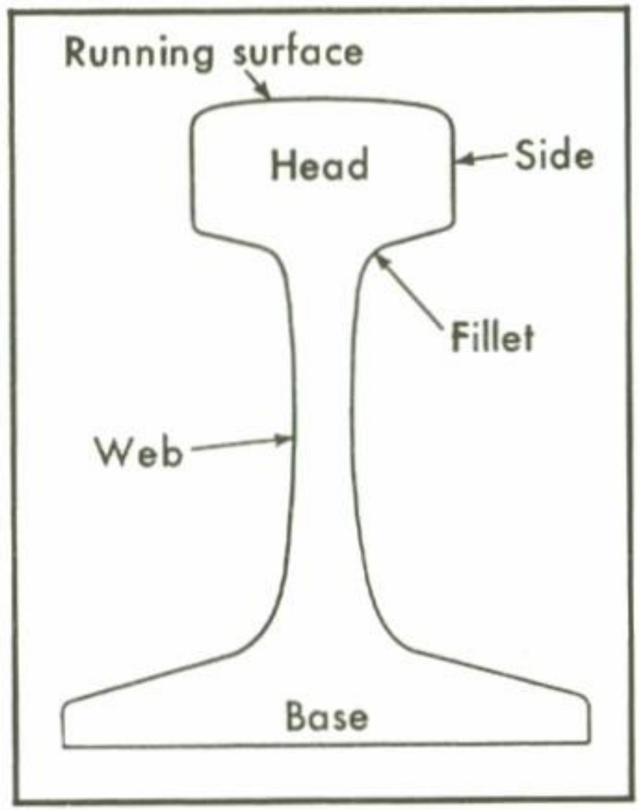
- Widely used when speed is 300 km/h or higher

Rail

- High smoothness requirement
- Require high quality track base and strong track structure components
- High quality rail
  - Pure
  - Smooth surface
  - Geometric precision
  - Straight

Rail design

- Weight
- Rail base width
- Head height
- Base height
- Web width

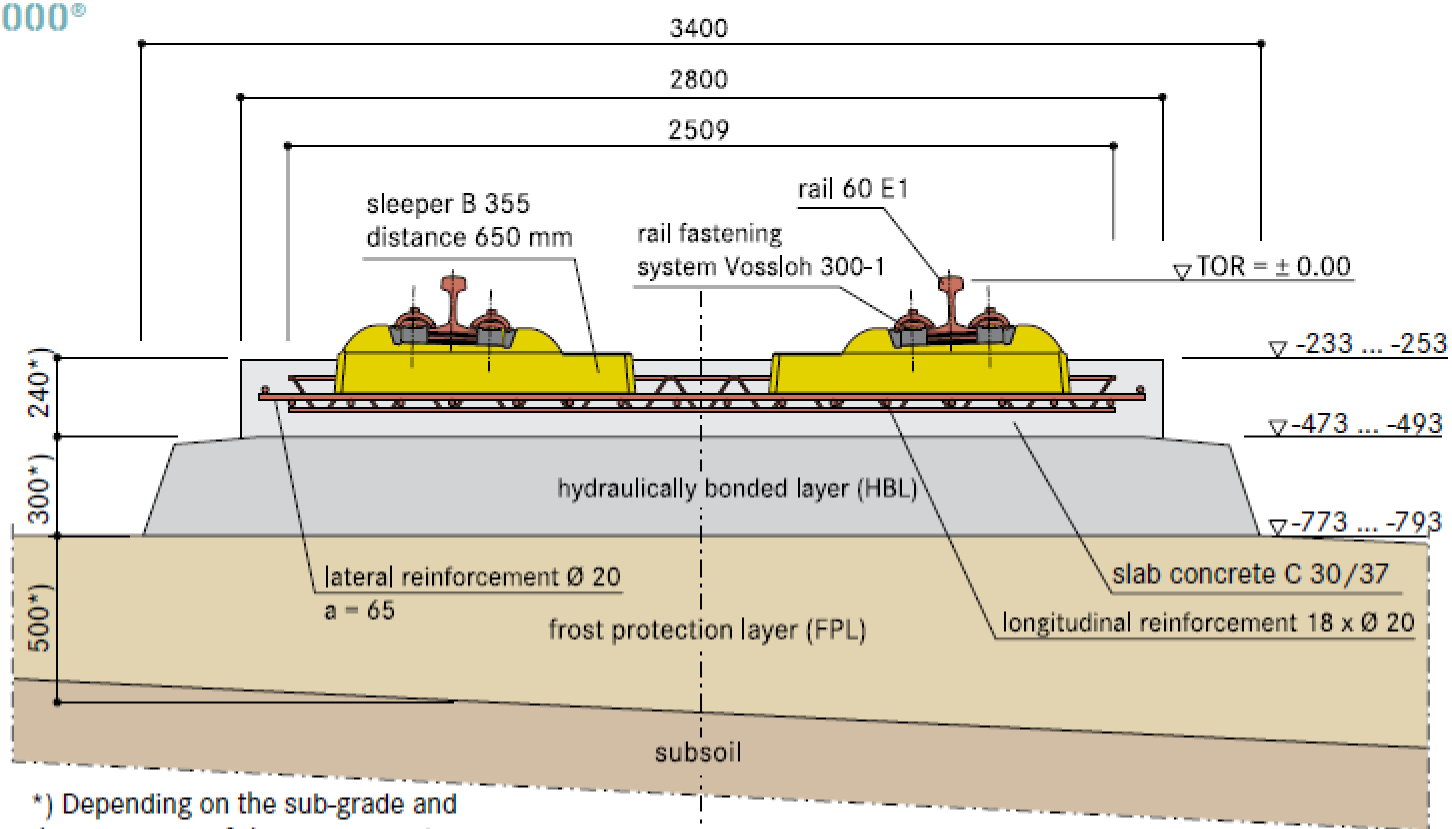


- Increase rail height
- Increase base width
- Height/base width<1.14-1.20

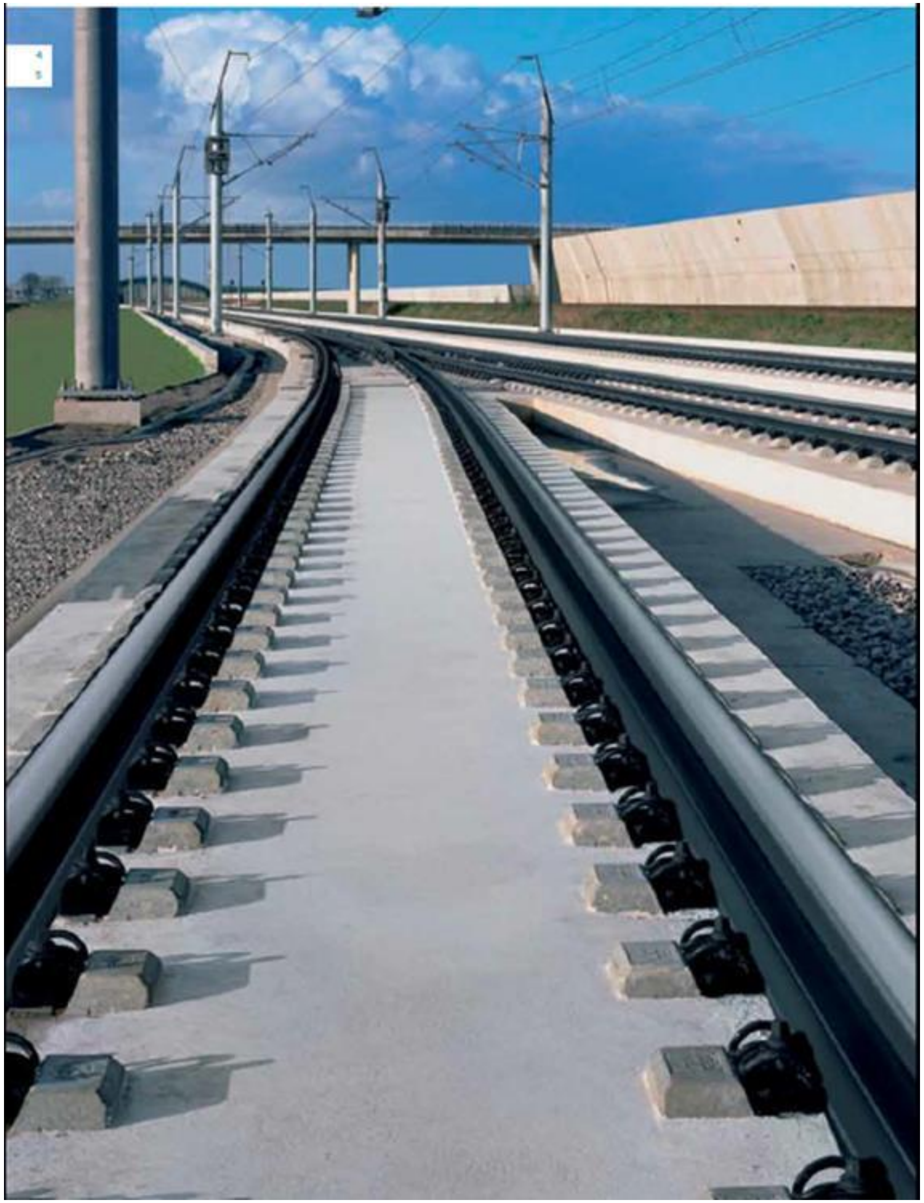
Ballastless track

- 30+ types
- Used on bridges and tunnel
  - Rheda 2000
  - Slab

RHEDA 2000®



*) Depending on the sub-grade and
the properties of the supporting layer

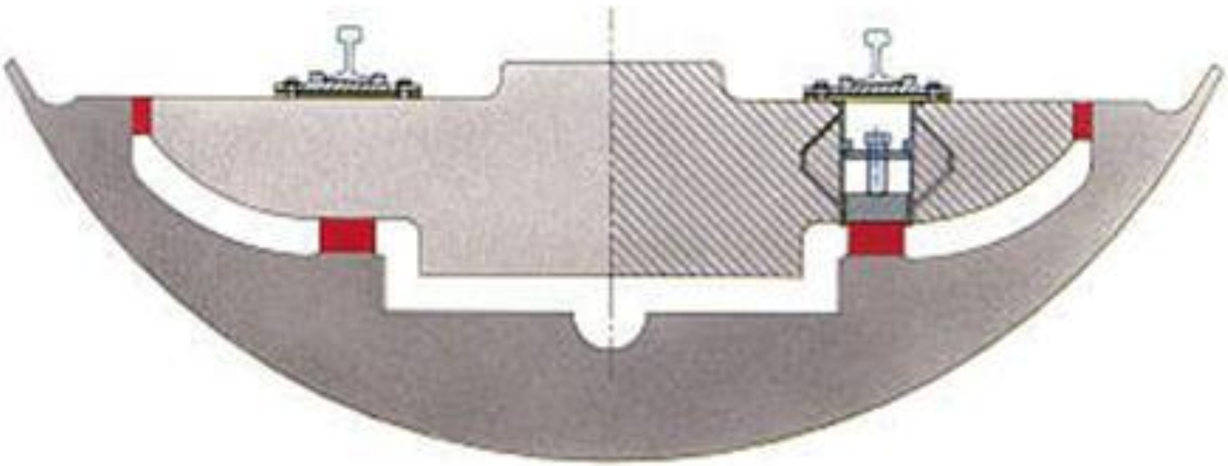


- Unique manufacturing structure
- With same structure, it can be used in tunnel, rail track, bridge, turnout, and thermal adjustment areas
- Lower construction height
- Lower construction cost

Slab track

- Primarily in Japan

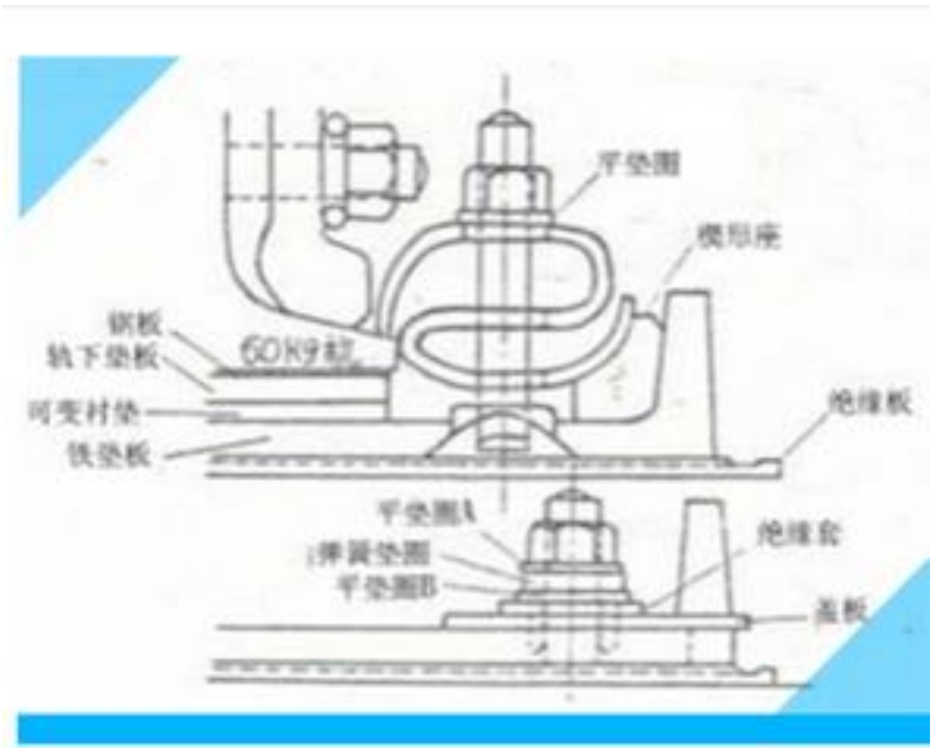
Floating slab track

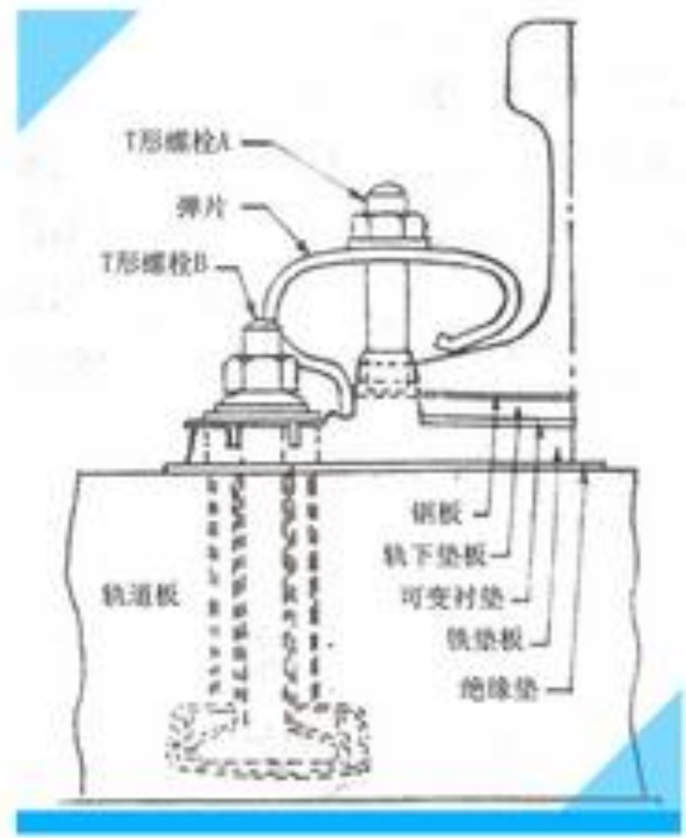


Fastening

- Ballast track
  - Connect rail and tie
  - Sustain load
- Ballastless track
  - Most important element for track elastic and adjustment

Elastic fastening - Japan





Elastic fastening - Germany

Figure 8.25: Vossloh fastening system

Elastic fastening - British

Figure 8.23: Pandrol fastening system

Figure 8.24: Pandrol Fastclip

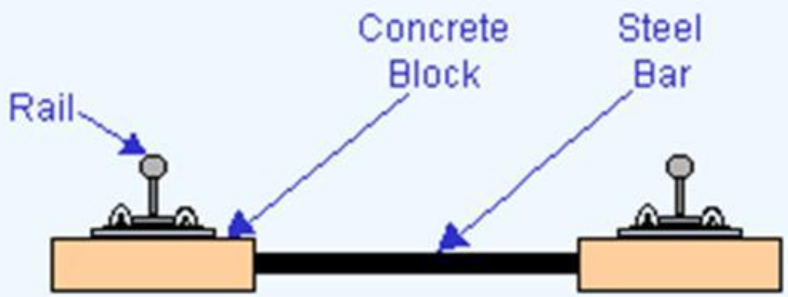
Tie

- Ballastless track is increasing
- Ballast track is still the majority
  - Concrete tie
  - Pros:
    - Lateral and longitudinal resistance is high
    - Stable
    - Materials for concrete is vast
    - Size is uniform, making elastic uniform
    - Not influenced by weather, fire, and insect
    - Endurable, long life
  - Cons:
    - Heavy
    - Elastic weak
    - Track bed required high quality
    - Thickness high
    - Absorbing layer

Tie Type

- Slab track (Japan and Germany)
- Concrete block tie

Concrete block ties



Twin block track form using a sleeper with two cast concrete blocks held to gauge by a steel bar. The system is favoured by the French and is also known by the names Sonneville block or Stedef track. It has the advantage of being lighter than standard concrete sleepers and the four faces of the two blocks resist movement better.

Tie Comparison

表 2.7　国外主要高速铁路混凝土轨枕结构形式及适用范围

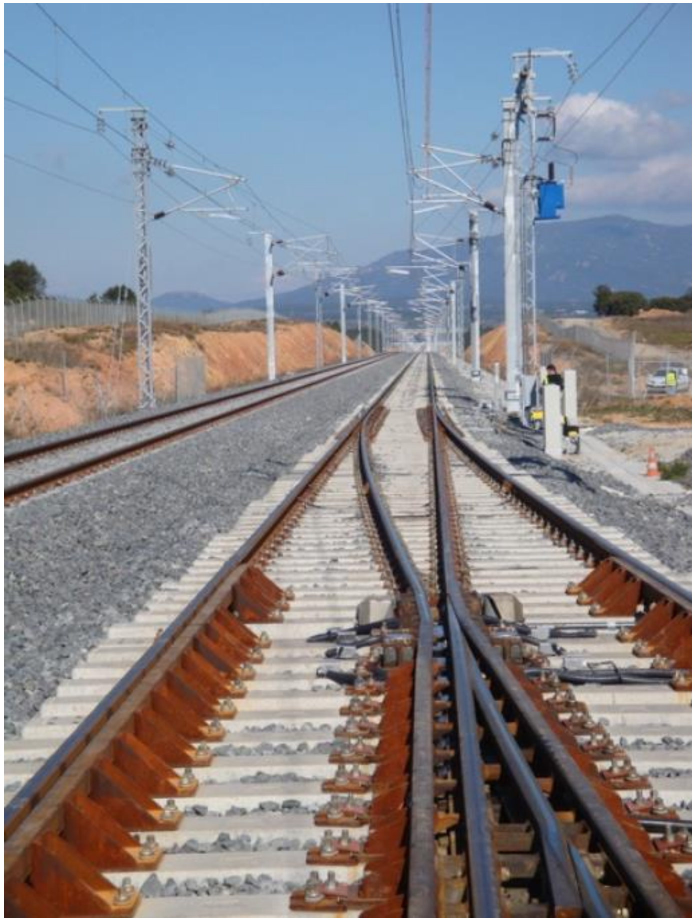
国别	轨枕形式	轨枕型号	长度(mm)	轨下断面尺寸		中间断面尺寸		枕底面积(cm^2)	重量(kg)	预应力筋		列车最高速度(km/h)
				高度(mm)	底面(mm)	高度(mm)	底面(mm)			根数	重量(kg)	
日本	整体式	3T	2 400	190	283	175	230	6 430	260	16	6.00	210
		3H	2 400	220	310.5	195	250	7 040	325	20	7.50	210～270
		4H	2 400	220	300	195	250	7 040	325		9.98	
德国	整体式	B70W	2 600	210	300	175	220	5 930	304		6.42	250
		B90W	2 600	210	320	180	240	6 680	330		6.42	
		B75	2 800	240	330	200	290	7 560	380		6.42	
法国	双块式	U31	2 245	220	290	块长	680	3 944	218	—	—	160
		U41	2 415	220	290		840	4 872	248	—	—	300

Ballast track

- Ballast abrasion and pulverization
  - High grade
- Choose ballast to have high stiffness
- Aggregate size uniform
- Geotexture layer

Turnout

- Turnout with no high speed diverging
- Turnout with high speed diverging



Long Continuous Welded Rail through Stations

- Glued insulated rail joint
- Seamless Turnouts
- CWR on bridge

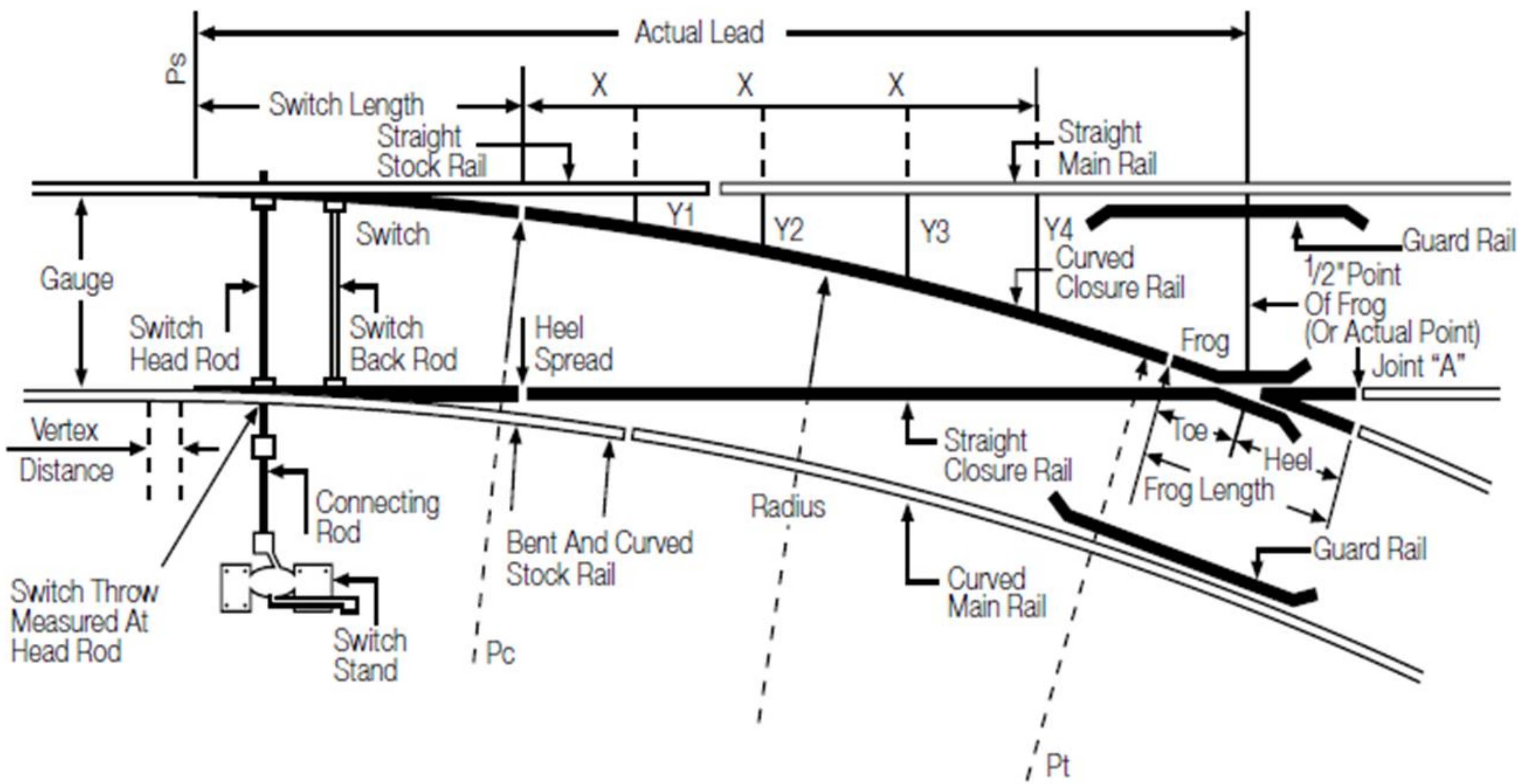
Glued insulated rail joint

Glued insulated rail joint

- Pro:
  - Integrated
  - High strength
  - High stiffness
  - Good insulation
  - Long life
  - Less maintenance

- Cons:
  - Not to take rapture
  - Lack of plasticity
  - Not for bending and collision

Seamless Turnouts



- Thermal impact

CWR on bridge

- Forces on surface
  - Dynamic force
  - Lateral force
  - Longitudinal force
- Interaction with bridge
  - Expansion and contraction of bridge
  - Bending

Force analysis

- Expansion/construction force
- Broken rail force
- Brake force
- Bending force

Seamless turnout on bridge

One time CWR vs two phase CWR

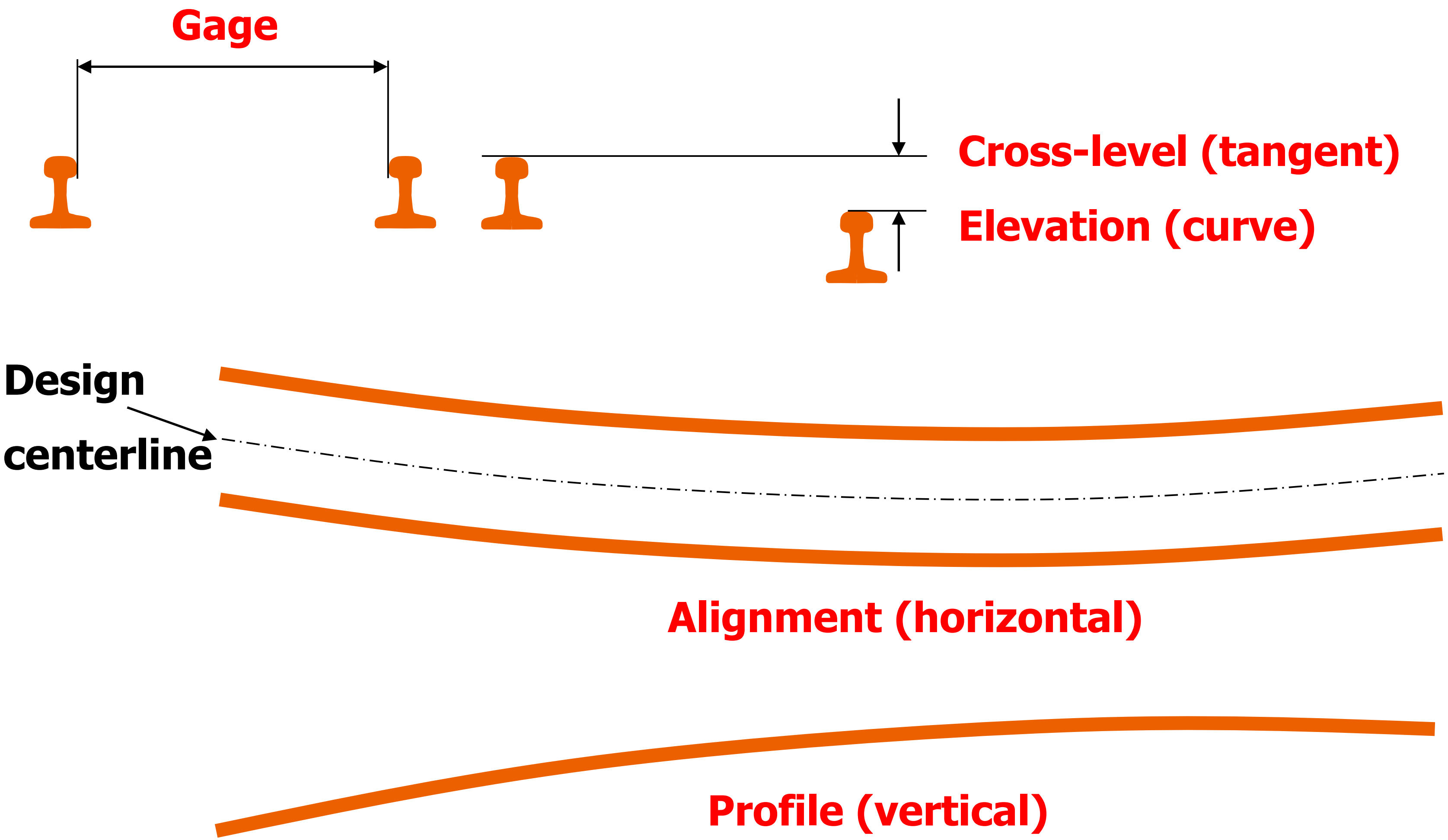
- Two phase CWR
  - Fully CWR after road bed is settled
- One time CWR requires high quality track

Track geometry irregularity management and information system

- Track geometry irregularity
  - Cross level
  - Elevation
  - Alignment and profile
  - Triangular dent
  - gauge

Figure 16.51: High speed track recording coach EM 250 of ÖBB

Track Geometry



Inspection

- Static inspection
- Dynamic inspection

Track geometry irregularity management - Japan

- Inspection once in 10 days
  - Over urgency standards, repair immediately
  - Over maintenance standards, repair in 10 days
  - Identify track weak sections, 20th each month, develop maintenance plan

- P value: number of inspection points that are over ±3 mm

Track geometry irregularity management - Japan

- Five categories of irregularity level
  - Acceptance target
  - Planned maintenance daily criteria
  - Comfort management target
  - Safety management target
  - Slow order target
  - 40m cord criteria

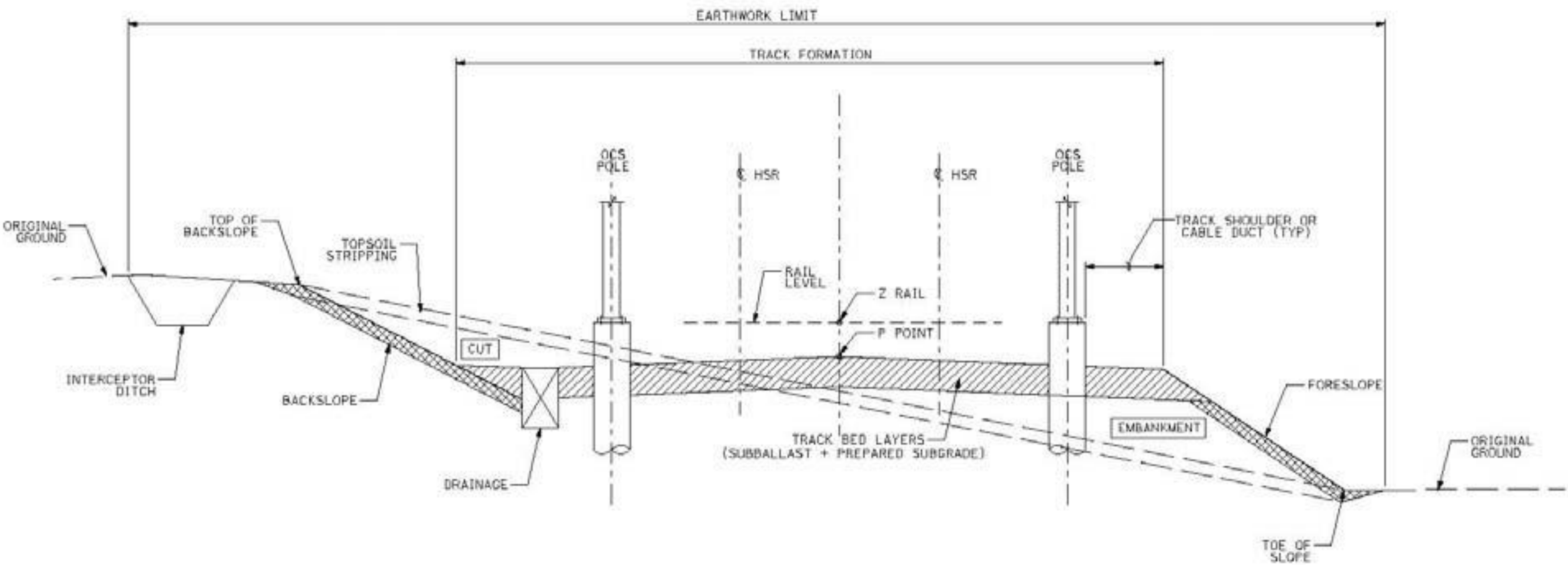
Track geometry irregularity management - France

Track geometry irregularity management - Germany

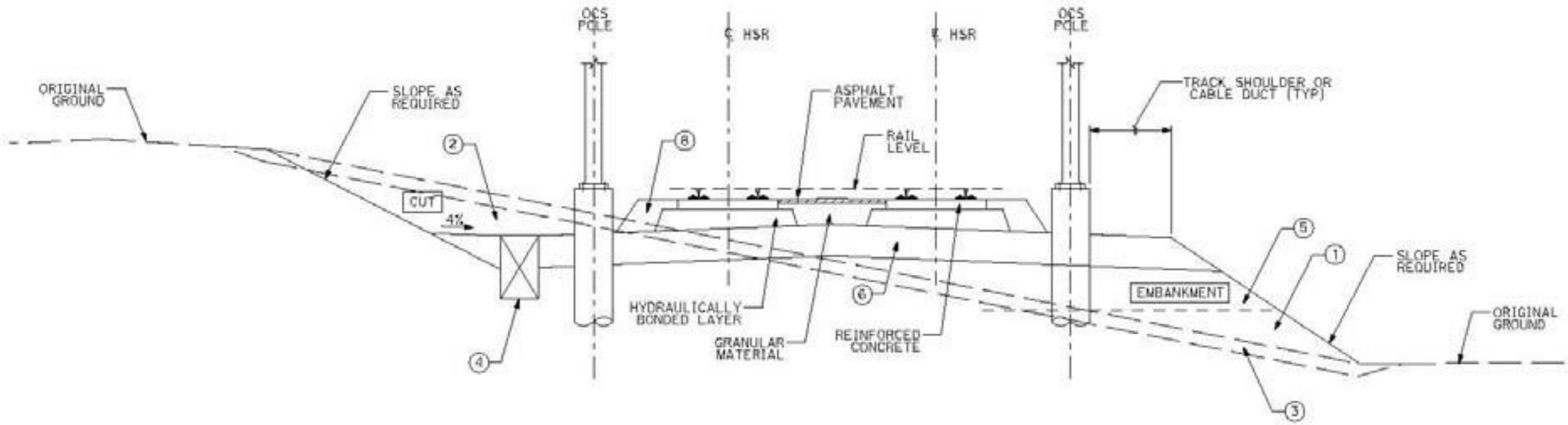
Track geometry irregularity management - China

Earthwork and Track Bed Design

General earthwork terms



Ballastless track



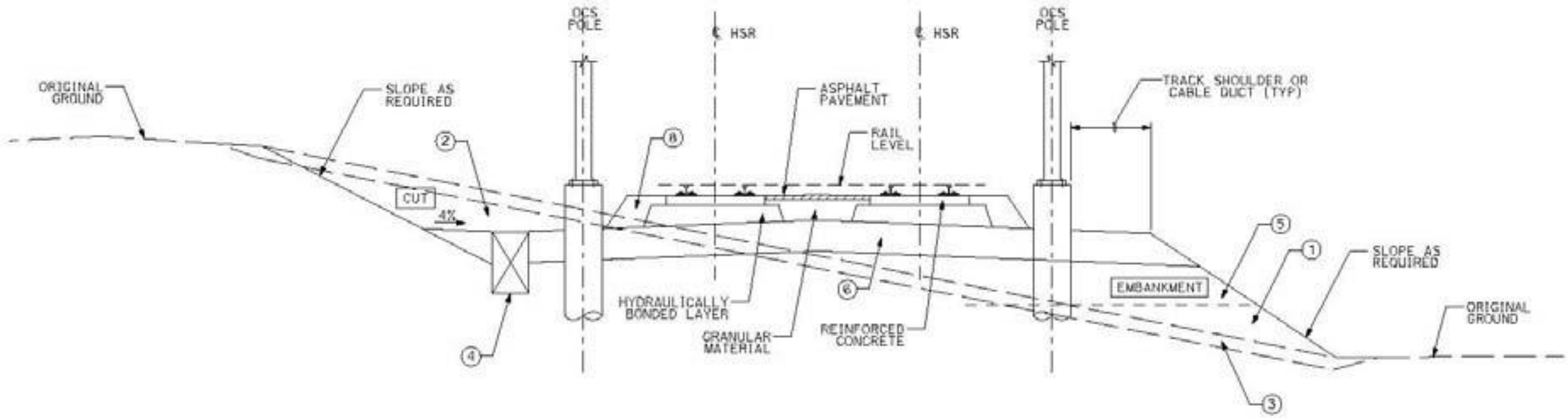
LEGEND

① EMBANKMENT - FILL
② CUTTING
③ TOPSOIL STRIPPING
④ DRAINAGE
⑤ UPPER PART OF EMBANKMENT
⑥ PREPARED SUBGRADE
⑦ SUBBALLAST LAYER
⑧ BALLAST

⑤ + ⑥ SUBGRADE

⑥ + ⑦ + ⑧ TRACK BED LAYERS

Ballast track



LEGEND

1. EMBANKMENT - FILL
2. CUTTING
3. TOPSOIL STRIPPING
4. DRAINAGE
5. UPPER PART OF EMBANKMENT
6. PREPARED SUBGRADE
7. SUBBALLAST LAYER
8. BALLAST

(5) + (6) SUBGRADE

(6) + (7) + (8) TRACK BED LAYERS

General Design Requirements

- Include ways to meet the environmental constraints
- To anticipate all possible difficulties
- To achieve balanced cut/fill volumes
- To produce optimized structures from the technical, financial, time and environmental point of view

General Design Requirements (cont.)

1. Evaluate the probable ground condition
2. Define the geometry of the structure and right-of-way
3. Assess the cost and time of execution of works
4. Ensure the reliability of the work
5. Achieve well-balanced cut/fill volumes
6. Assess the potential risks during construction and in operation
7. Define performance targets for construction sufficiently explicit
8. Limit the costs of maintenance during operations.
9. Maximize technical and financial considerations for the structure at each phase: design, construction and maintenance during operation.

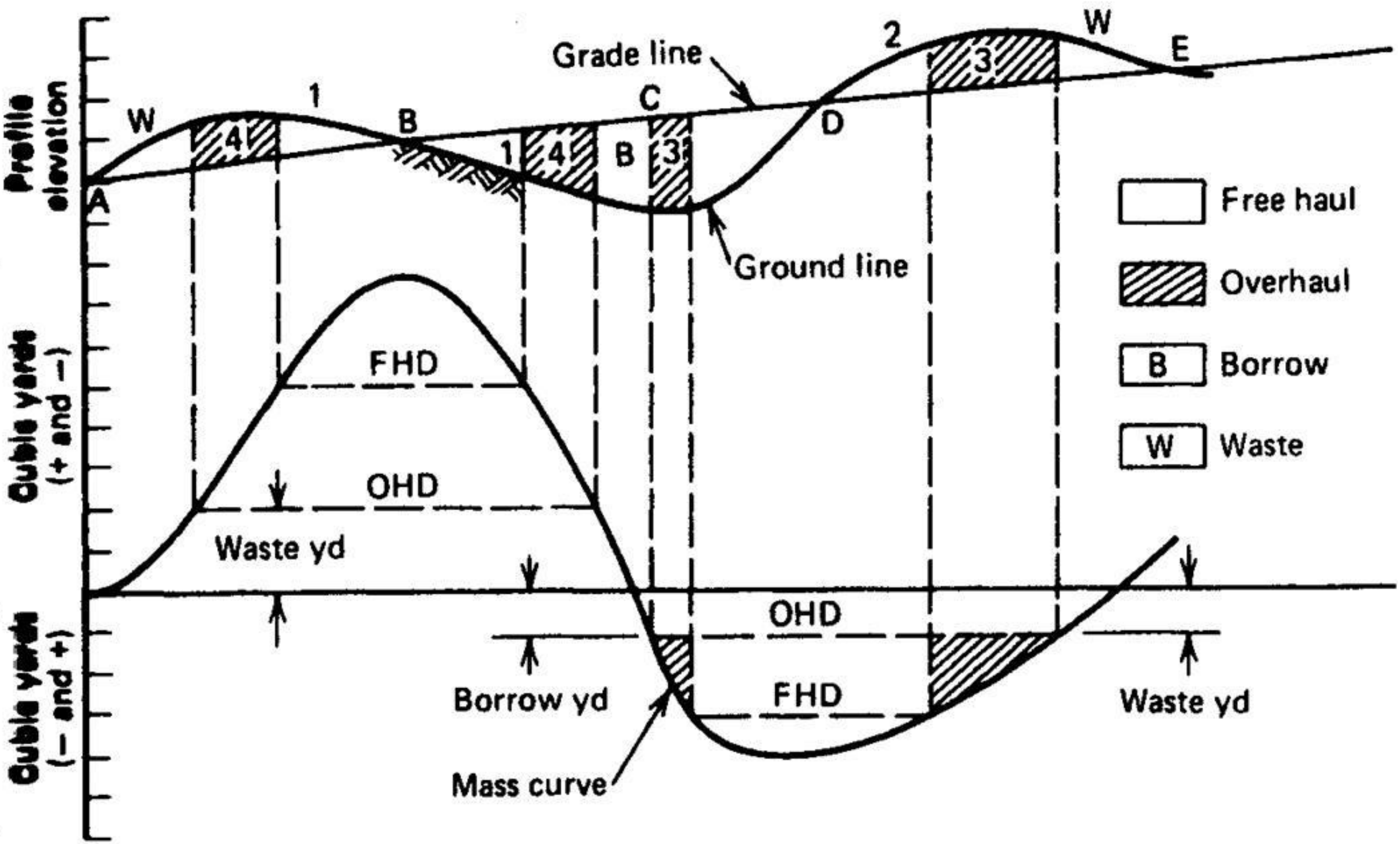


Figure 18.2. Mass diagram fragment.

Specific Elements to Consider During Design

- Geological and Geotechnical Investigation and Design
- Meteorological Design
- Hydraulic and Drainage Design
- Hydrogeologic Design

Classification of Soils and Subgrades

- Geotechnical Classification of Soil
- Classification of Subgrade according to Bearing Capacity
- Frost Susceptibility of Soils

Soil type

- Mineral soils
  - Particle size
  - Plasticity
  - Sensitivity to water
  - Mineral content
- Organic soils
- Mixed soils

Mineral – by particle size

Figure 3-1 – Example of a particle size distribution curve (logarithmic scale of abscissas)

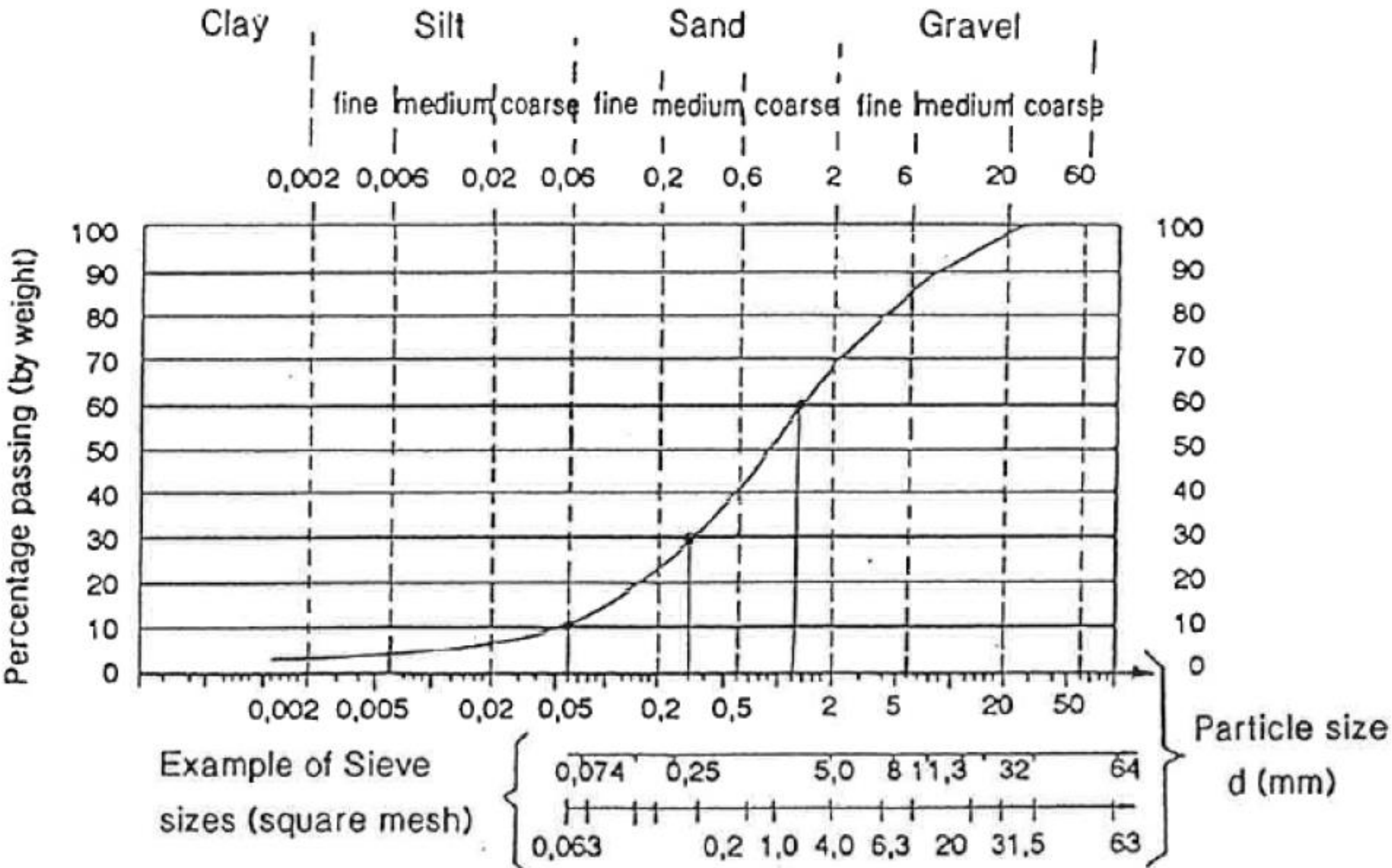


Figure 3-2 – Grain Size Classification (according to I.S.S.M.F.E recommendations of 1973)

Particle Class		Grain Size (mm)
Clay		< 0.002
Silt		0.002 – 0.06
	Fine	0.002 – 0.006
	Medium	0.006 – 0.02
	Coarse	0.02 – 0.06
Sand		0.06 – 2
	Fine	0.06 – 0.2
	Medium	0.2 – 0.6
	Coarse	0.6 - 2
Gravel		2 – 60
	Fine	2 – 6
	Medium	6 – 20
	Coarse	20 - 60
Cobbles		60 - 200
Boulders		> 200

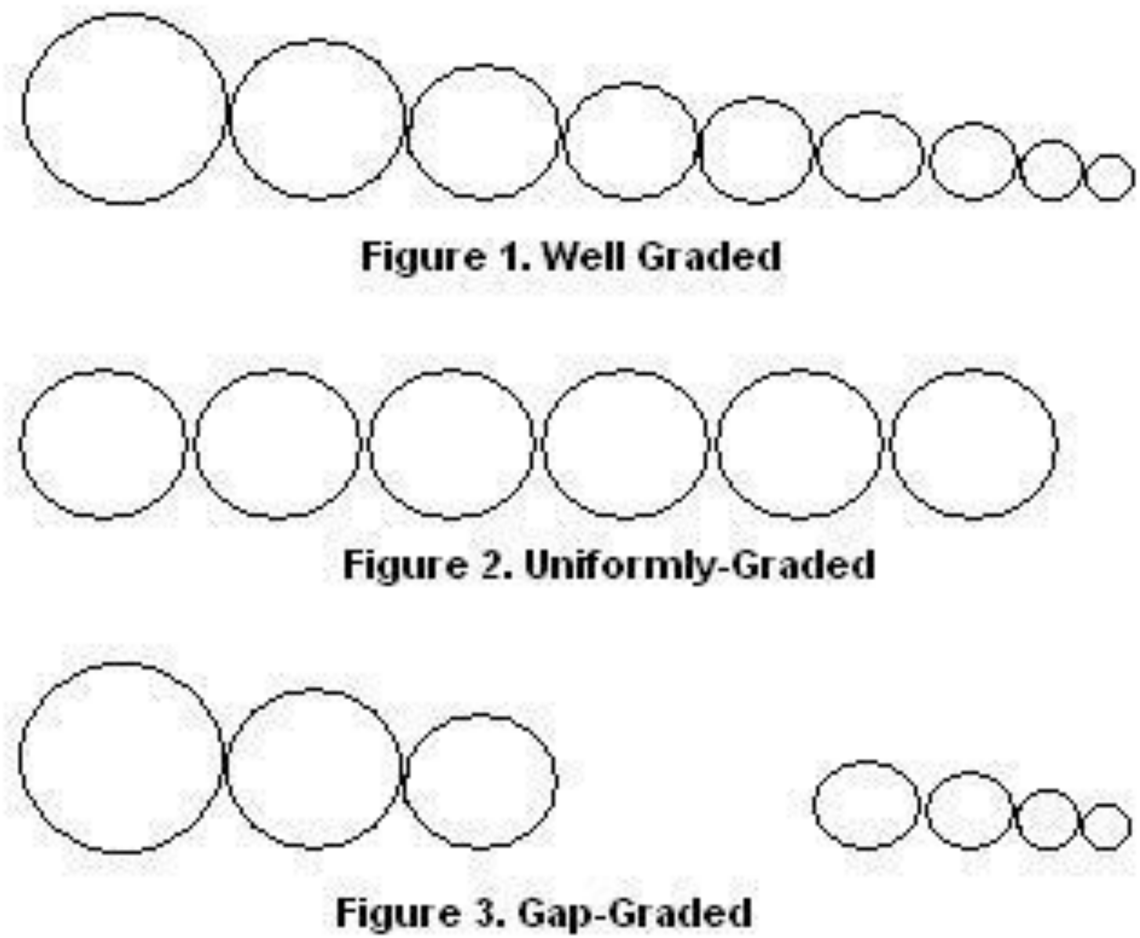
Uniformity and curvature coefficients

- Uniformity coefficient Cu
  - suitability for compaction
  - bearing capacity of the track bed layers closest to the underside of the sleepers
  - Cu>6, well graded

$$C_U = \frac{d60}{d10}$$

$$C_C = \frac{(d_{30})^2}{d_{60} + d_{10}}$$

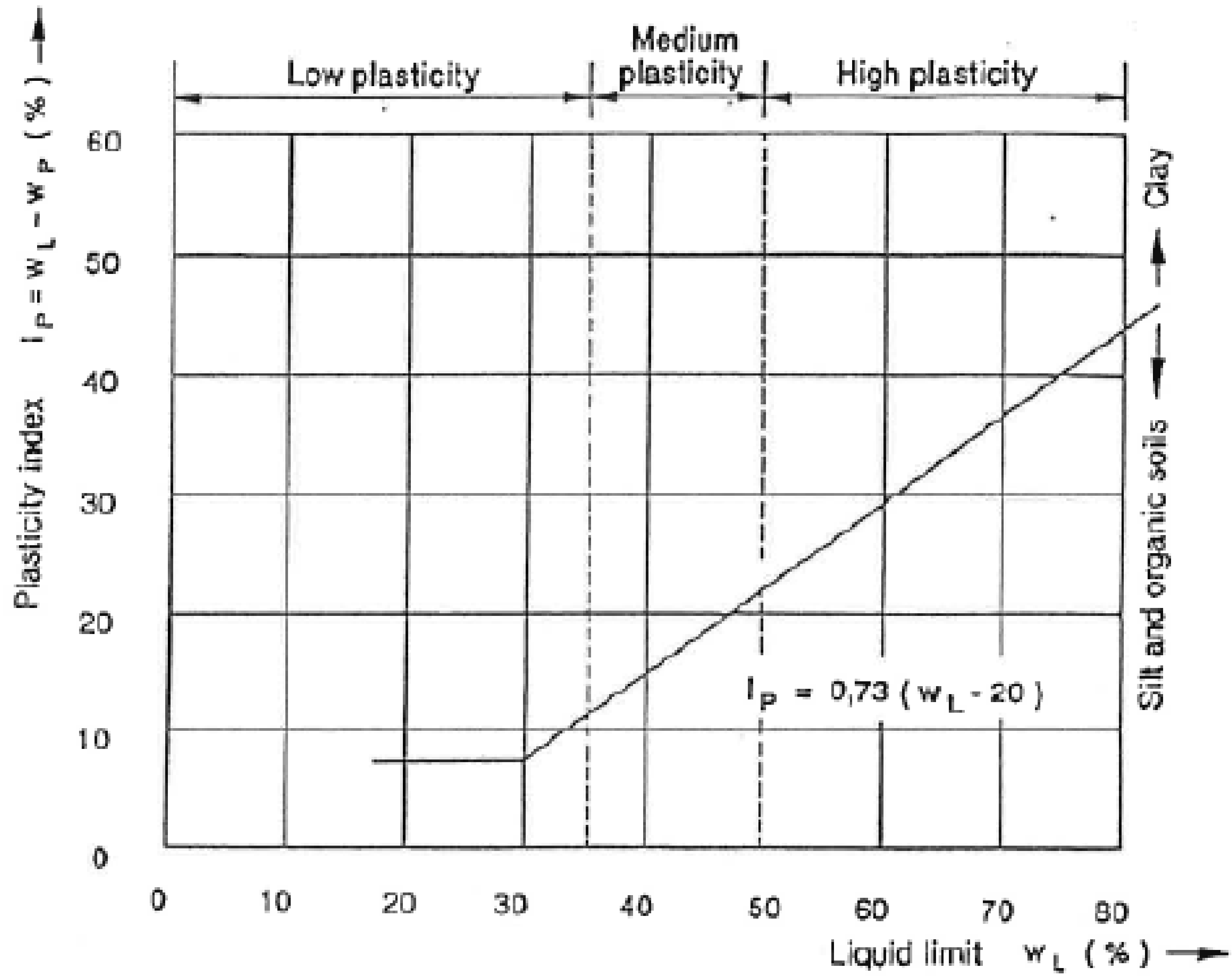
- Curvature coefficient Cc
  - Measure and symmetry and shape of the gradation curve
  - 1<Cc<3, well graded



- http://en.wikipedia.org/wiki/Soil_gradation#/media/File:Soil_Gradations.JPG

Plasticity

- Fine cohesive soil
- Atterberg limits
  - Liquid (LL)
  - Plastic limit (PL)
  - Plasticity index (PI=LL-PL)



- Plasticity Chart for the Classification of Fine Grained Soils (After Casagrade)

Sensitivity to water

- The sensitivity of clay to water is characterized by the Methylene blue test (bllue value Vb)
- The sensitivity of a soil to water is characterized by the clay content (Vbs)
- When Vbs<0.1, the soil is said to be insensitive to water
- When Vbs>0.2, the soil is sensitive to water

Mineral content

- Quartz sand
- Mica sand
- Olivine sand
- Fine marl, according to the CaCO3

Organic soil

- Organic soils are the result mainly of the decomposition of vegetable or animal remain
- The main groups are: topsol, peat, organic soils (OH and OL)
- Tested for: moisture content, liquid limit plasticity index, strength and compressibility

Mixtures of mineral and organic soils

Figure 3-4 – Classification of Mixtures of Mineral and Organic Soils

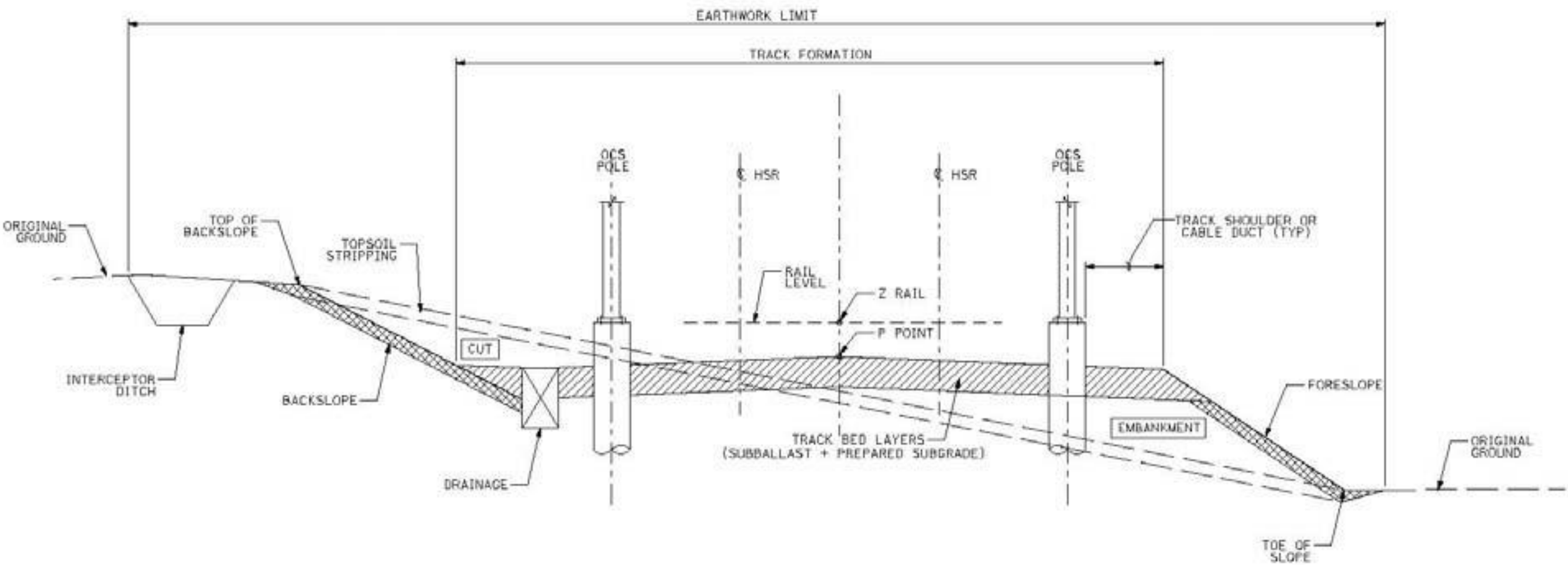
Description of the soil	Percentage by dry weight of organic content
Mineral soils	≤ 1 %
Soils containing some organic matter	> 1 % et ≤ 5 %
Mixed mineral/ organic soils	> 5 % et < 30 %
Organic oils	≥ 30 %

Note: Some railways use different values.

Classification of subgrade according to bearing capacity

- Determine the quality of each soil type contained in the subgrade
- Determine the bearing capacity of the whole system: subgrade + prepared subgrade+ subsoil

General earthwork terms



Soil quality classes

- Geotechnical properties of the soil
- Local hydrogeological and hydrological conditions
  - The uppermost layer of soil is above the level of highest natural **ground water**
  - There is no harmful natural transverse, longitudinal or vertical water flow in the subgrade
  - Rainwater is correctly drained from the subgrade, and the longitudinal or transverse drainage system is in proper working order

Soil Type (Geotechnical Classification)	Soil Quality Class
0.1 Organic soils (OH and OL) 0.2 Soft soils containing more than 15% fines [(1),] with a high moisture content therefore unsuitable for compaction. 0.3 Thixotropic soils [(2)] (e.g. quick-clay) 0.4 Soils containing soluble material (e.g. rock salt or gypsum) 0.5 Contaminated ground (e.g. industrial waste) 0.6 Mixed material / organic soils [(2)]	**SQ 0**
1.1 Soils containing more than 40% of fines [(1)] (except for soils classified under 0.2) 1.2 Rocks which are very susceptible to weathering, e.g.: - Chalk with ρ_d < (1.7 t/m^3) 106 pcf and high friability - Marl - Weathered shale	**SQ 1**
1.3 Soils containing 15 to 40% of fines [(1)] (except for soils classified under 0.2) 1.4 Rocks which are moderately susceptible to weathering, e.g.: - Chalk with ρ_d < (1.7 t/m^3) 106 pcf and low friability - unweathered shale 1.5 Soft Rocks, e.g. Microdeval wet (MDE) > 40 and 1.6 Los Angeles (LA) > 40	**SQ 1** [(3)]
2.1 Soils containing from 5 to 15% of fines [(1)] 2.2 Uniform soil containing less than 5% of fines (1) (CU ≤ 6) 2.3 Moderately hard rock, e.g. if 25 < MDE ≤ 40 and 30 < LA < 40	**SQ 2** [(4)]
3.1 Well graded soils containing less than 5% of fines [(1)] 3.2 Hard rock, e.g.: if MDE ≤ 25 and LA ≤ 30	**SQ 3**

Bearing capacity of the subgrade

- Quality class of the soil which forms an embankment
- Quality and thickness of the prepared subgrade
  - P1: poor subgrade – deformation modulus ≤ 20 MPa (2.9 ksi)
  - P2: average sugrade – deformation modulus ≤ 50 MPa (7.25 ksi)
  - P3: good subgrade – deformation modulus ≤ 80 MPa (11.6 ksi)

Figure 9 – Determination of the Bearing Capacity of the Subgrade

Quality Class of the Soil	Class of Bearing Required for the Prepared Subgrade	Requirement of Subballast Layer	
		Quality Class	Min. Thickness of Trackbed (in)
SQ 1	P1	SQ1	-
	P2	SQ2	20
	P2	SQ3	15
	P3	SQ3	20
SQ 2	P2	SQ2	15
	P3	SQ3	
SQ 3	P3	SQ3	-

Frost susceptibility of soils

- Soil type based on frost susceptibility
  - Not susceptible to frost
  - Susceptible to frost
  - Very susceptible to frost

Figure 10 – Frost Susceptibility of the various Soils Types

Degree of Frost Susceptibility	Soil Type
Not susceptible to frost	Sand Gravel
Susceptible to frost	Clay
Very susceptible to frost	Silt

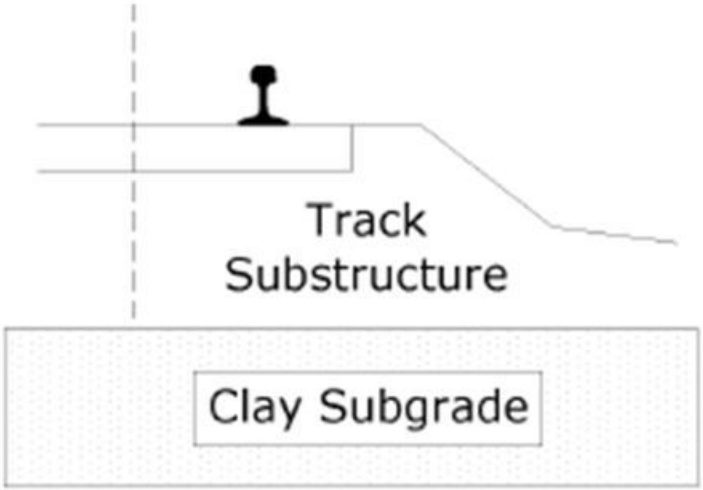


Figure 4-7 Stable Site

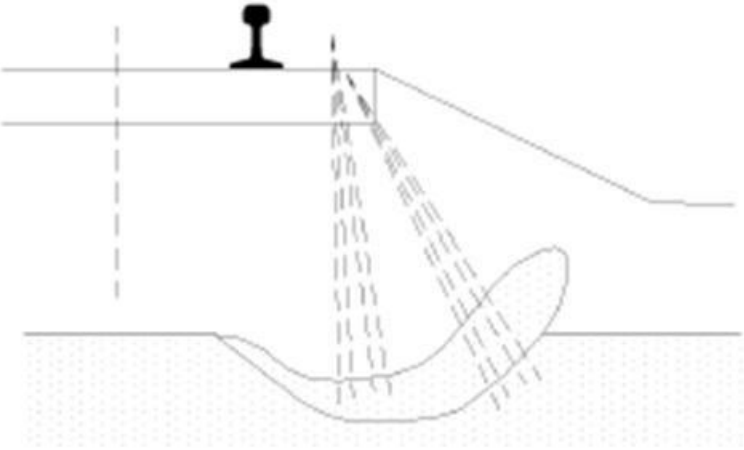


Figure 4-9 Growth of Heave

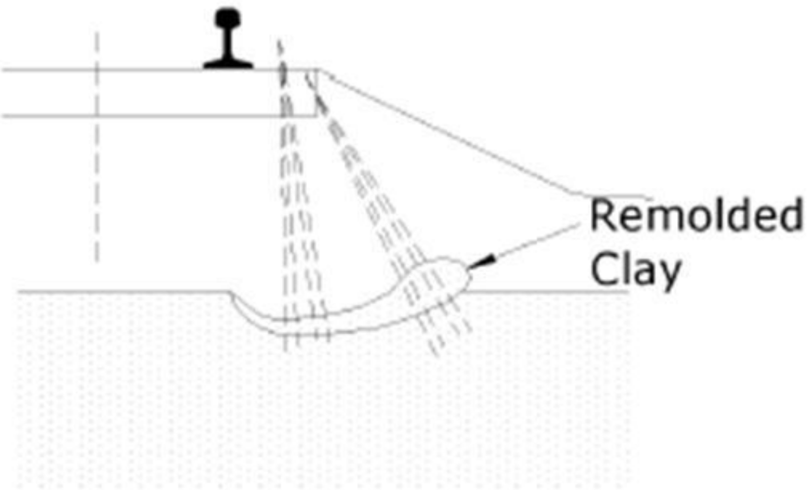


Figure 4-8 Onset of Instability

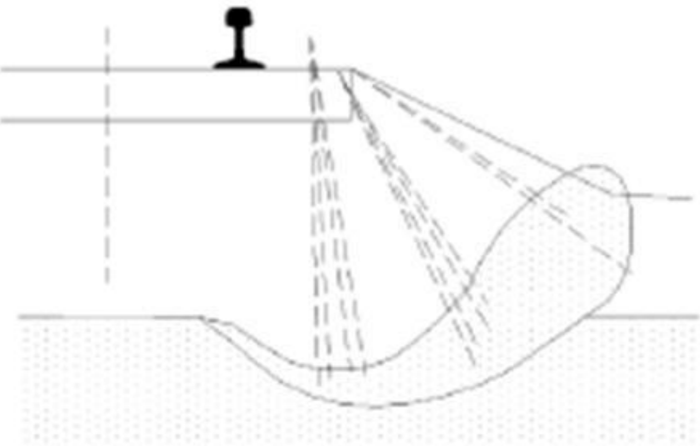


Figure 4-10 Surface Manifestation of Heave

Frost susceptibility of soils (cont.)

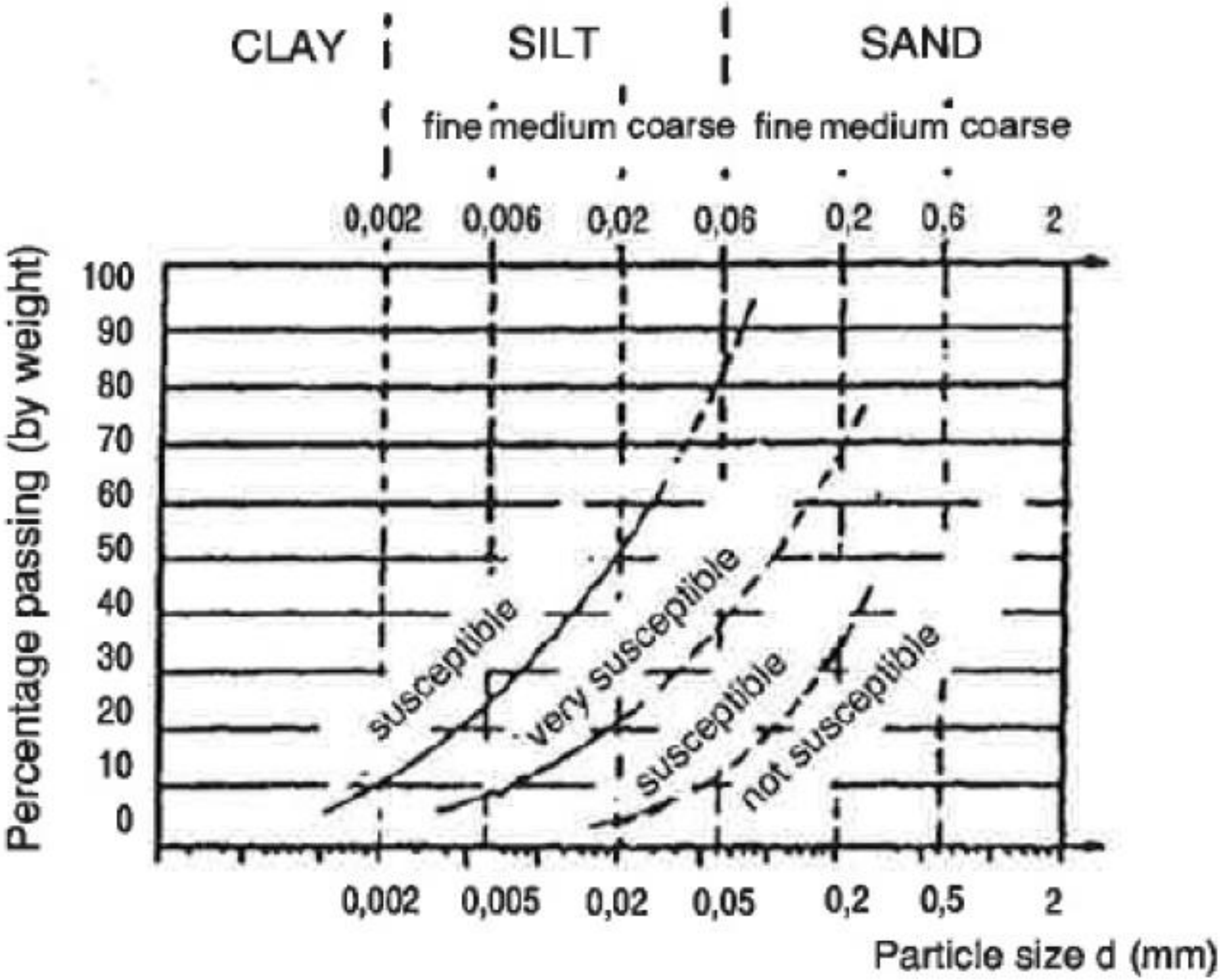
- A soil composed mainly of coarse particle will become frost-susceptible when the percentage of clay or silt rises above a certain critical level.

Figure 11 – Percentage of fine particles (d < 0.02 mm) according to the Uniformity Coefficient

Uniformity coefficient C_U of the soil under consideration	Critical percentage (by Weight) of particles with a diameter d >0.02mm
5	10
15	3

Frost susceptibility of soils (cont.)

- The degree of frost susceptibility can be estimated by the capillarity of the soil layer
- If the capillary rise of water is > 0.7 m (23 in.), the soil layer can be considered frost susceptible
- In track bed layers, the capillary rise of water shall be < 0.3 m (12 in.)

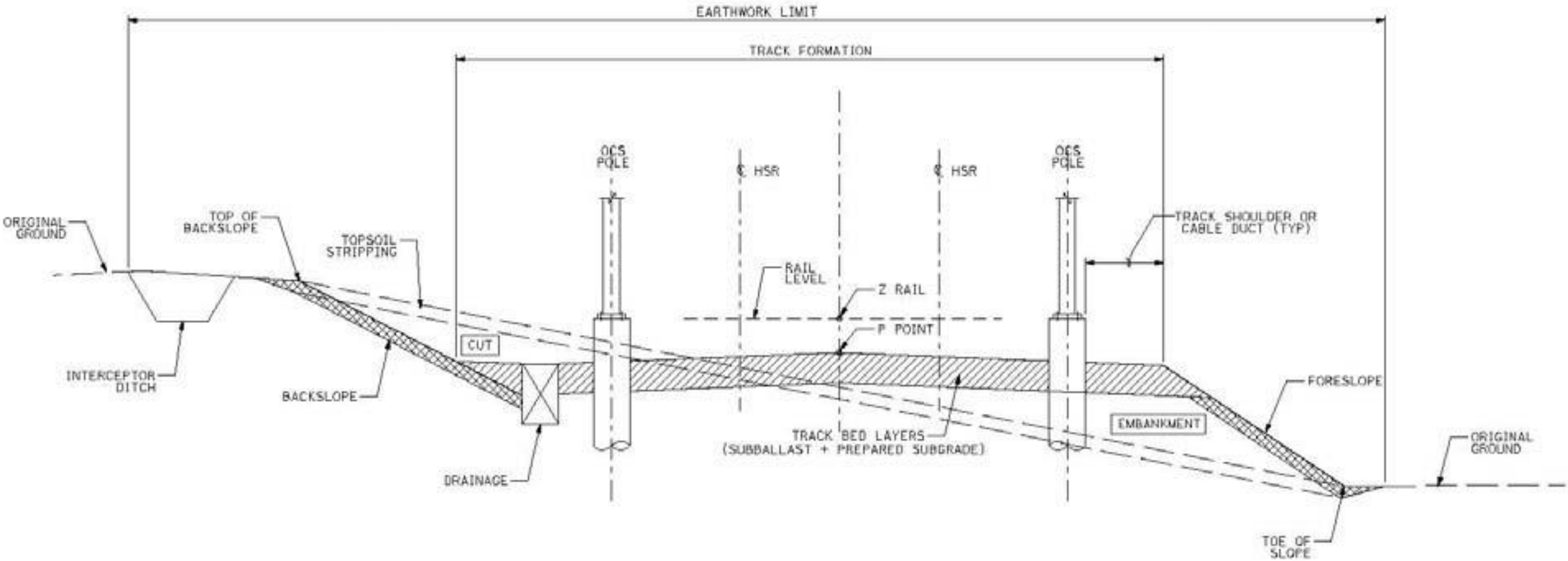


CLAY
SILT
SAND
fine
medium
coarse
fine
medium
coarse
0,002
0,006
0,02
0,06
0,2
0,6
2
Percentage passing (by weight)
100
90
80
70
60
50
40
30
20
10
0
susceptible
very susceptible
susceptible
not susceptible
0,002
0,005
0,02
0,05
0,2
0,5
2
Particle size d (mm)

Earthwork and Track Bed

- Suitability of soils for re-use
- Design and construction of earthwork
- Composition and thickness of the track bed layer

General earthwork terms



Stability Analysis of Earthwork

- Stability: resistance to slope failure must be demonstrated by calculation
- Settlement:
  - How fast construction can proceed
  - Demonstrate that any settlement after the line is open can be rectified by routine maintenance
  - If not, other alternative can be considered

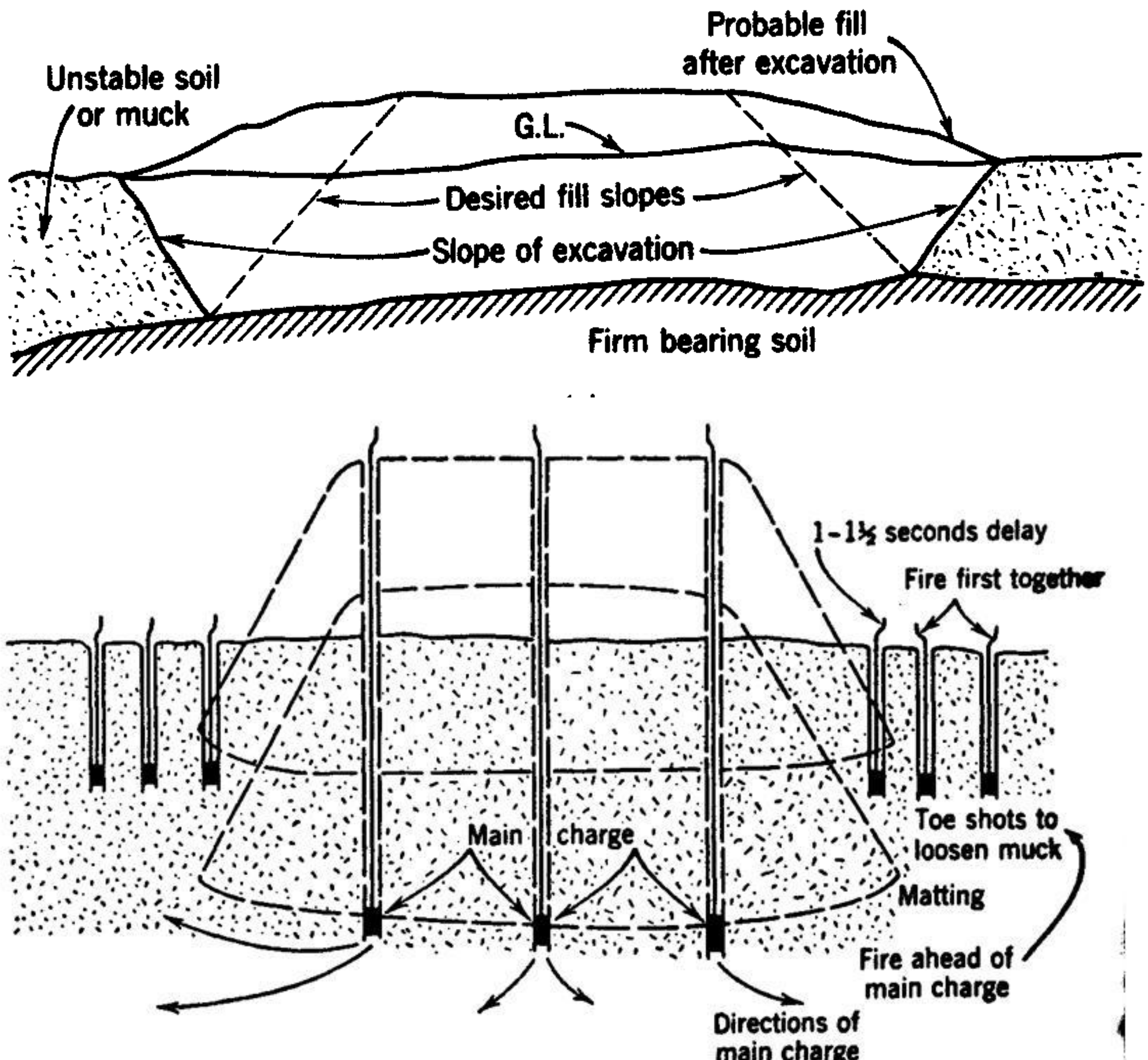


Figure 19.3. Blasting to accelerate subsidence.

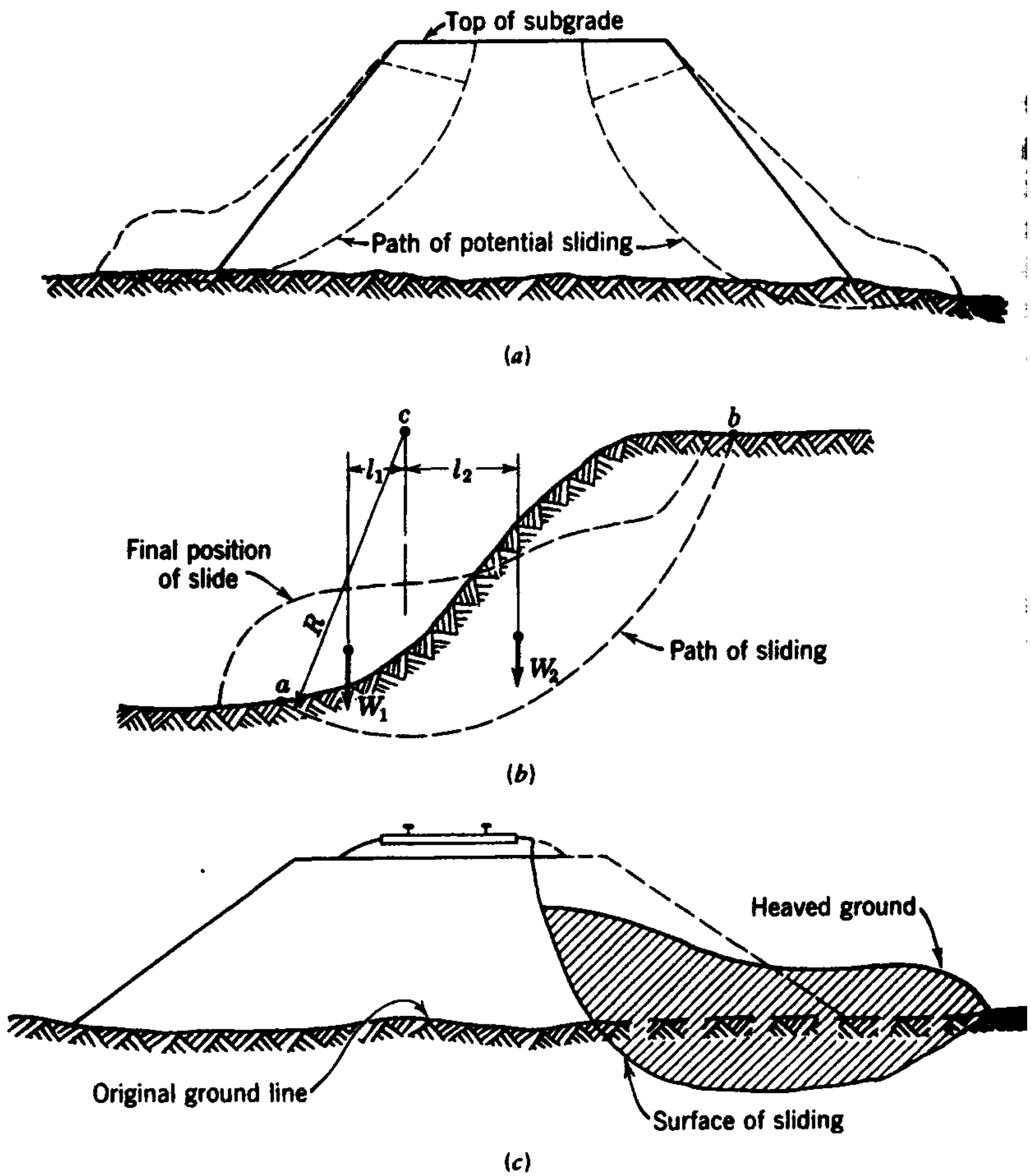


Figure 19.4. Slides due to failure in shear.

Stability Analysis of Earthwork (cont.)

- Slope angle
  - Embankment: 1.5H: 1V or 2H:1V (15% design)
  - Cuts
    - Intact rock not susceptible to weather and without unfavorable dip or cleavage: 45%-90%
    - Weathered rock subject to degradation and deterioration: special consideration
    - Granular soils: 1.5H:1V to 2H:1V
    - Cohesive soils: 1.5H:1V to 2H:1V
    - Pre-historic landslide areas: extensive evaluation

- Freight rail:
- 1.5:1 commonly used
- Sands or clay: 2:1 or 3:1
- Solid rock cuts: ½:1 or ¼:1
- Soil type is a determining factor
- Cut widening or slop flattening
- Terrace and setback

Stability Analysis of Earthwork (cont.)

- Sensitive soils or unfavorable hyrogeological conditions
  - Embankments
    - Replacement of the sensitive soil
    - Pre-loading for consolidation of the soil underlying the embankment
    - Installation of vertical drains or piles
  - Cuts
    - In ground which is sensitive to frost or water, cut slopes shall be protected by a coarse granular layer
    - …

Stability Analysis of Earthwork (cont.)

- Embankment fills
  - $\rho_d \geq$ 90% of the maximum dry density where embankment construction exceeds 5 ft in depth.
  - EV2 d ≥ 6.525 for the fine soils, or 8.7 ksi for sandy and gravelly soils
- Prepared subgrade:
  - $\rho_d \geq$ 95% of the maximum dry density as determined from ASTM D1557-07
  - EV2 d ≥ 11.6 ksi (dynamic deformation modulus)

Blanket

- Blanket is a layer of coarse grained material between ballast and subgrade, spread over entire width.
  - Improving the bearing capacity
  - Reduction of induced stresses
  - To prevent mud pumping and fouling of ballast by upward migration of fine particles from the subgrade
  - To prevent damage of subgrade by ballast
  - Shedding surface water from the ballast and drain away from the subgrade
  - Protection of subgrade against erosion and climatic variations

Blanket (cont.)

- In its most complete form, consisting of:
  - A sandy gravel sub-ballast layer
  - A “foundation” layer of well graded sandy gravel
  - A filtering layer of sand to be used only with a subgrade of bearing capacity class P1
  - A geotextile filter used with prepared subgrade P1 and P2

Filter blankets and geotextiles

Determination of the thickness of the track bed layers

- The ballast thickness is constant
- The dimensions of the track bed layers for the sub-ballast layer and the eventual prepared subgrade are also constant
- For 15% design, it is proposed to use an 8 inch thick sub-ballast layer and a 20 inch thick prepared subgrade, which is used in France.
- The criteria and the optimization of the thickness of these layers will be developed at a later design stage.

HSR Station

HSR Station Characteristics

- Service characteristics
  - No freight
  - No postal service
- Design characteristics
  - Track side → on the track,
    - entrance upper, exit lower
    - Tall
  - Coordinate with other modes

HSR Station Characteristics (cont.)

- Operation characteristics: High density, short length
  - Passenger management
    - Automatic ticketing system
    - Traveler information system
    - Passenger guidance system: car position, platform…
  - Train operation: trains of different speed share track
    - By-pass station

Type of Stations

- Bypass
- Intermediate
- Terminal (departure and arrival)

Station Technical Characteristics

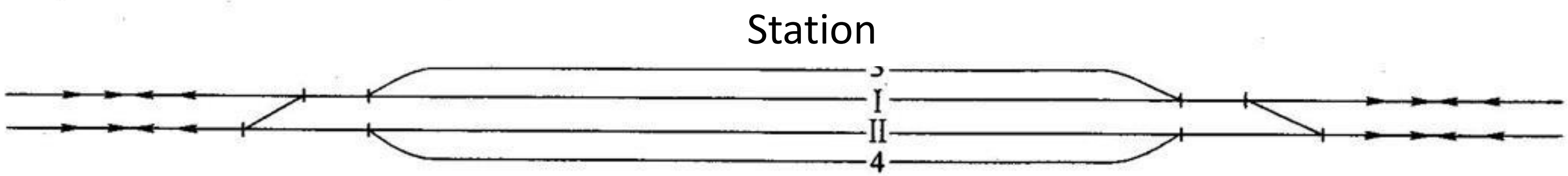
- Tracks and spacing
  - Track (#, length)
    - Mainline
    - Siding
    - …
  - Track spacing

Station Technical Characteristics (cont.)

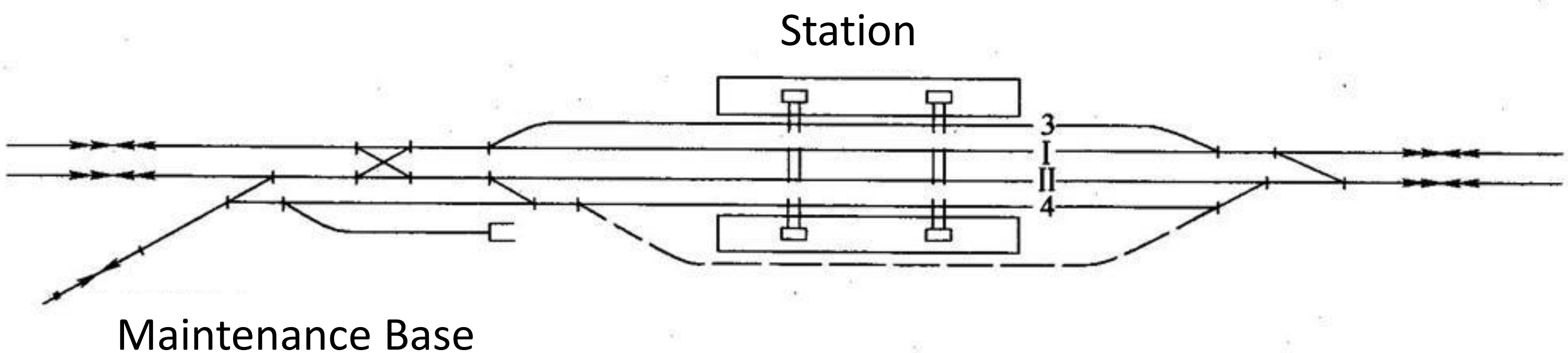
- Passenger service facilities
  - Waiting room
  - Platform (height…)
  - Shelter
  - Entrance and exits (bridge and tunnel)
  - Safety monitoring

Station Technical Characteristics (cont.)

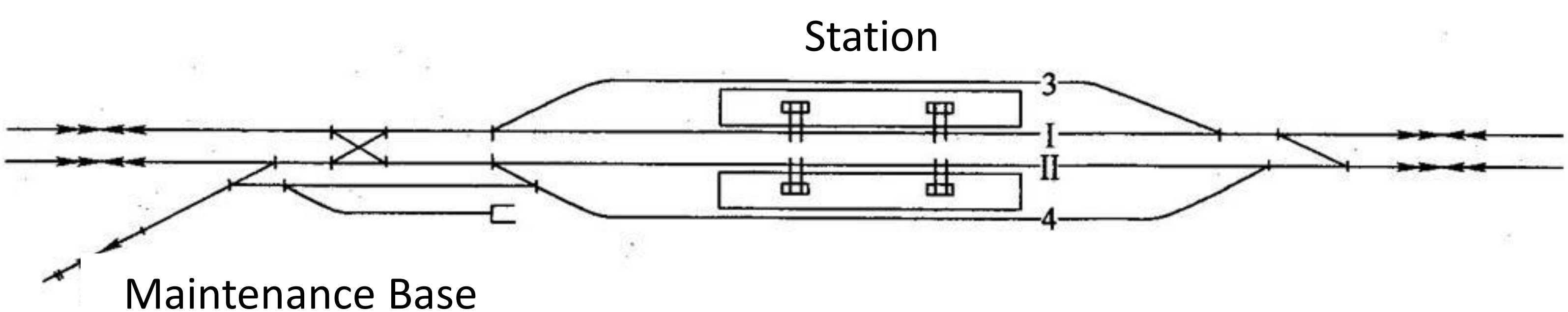
- Layout
  - Two tracks
  - Two tracks two platforms
    - Symmetric
    - Island
  - With maintenance facilities
  - Two platforms four tracks



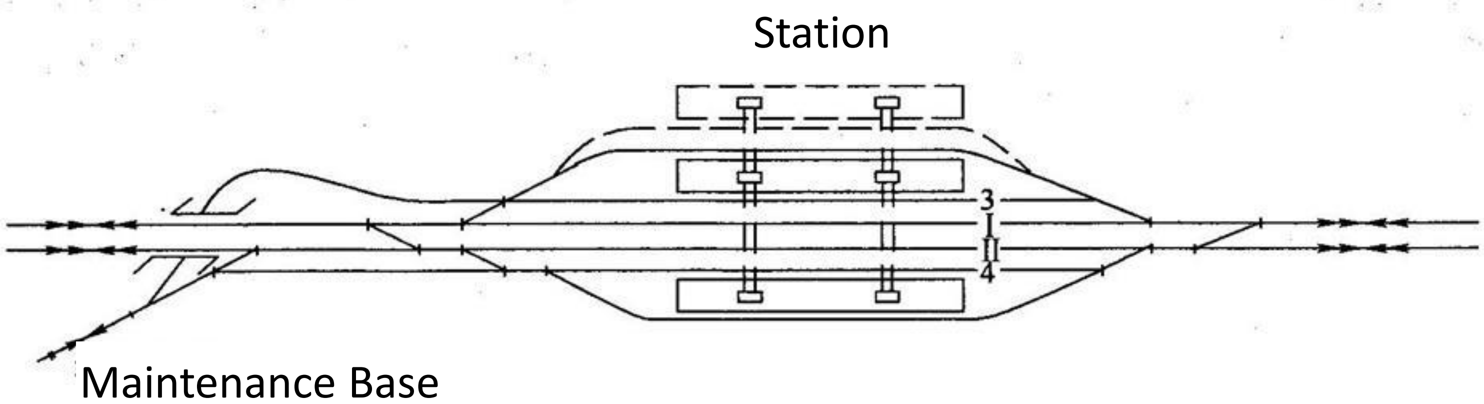
Two Line Station



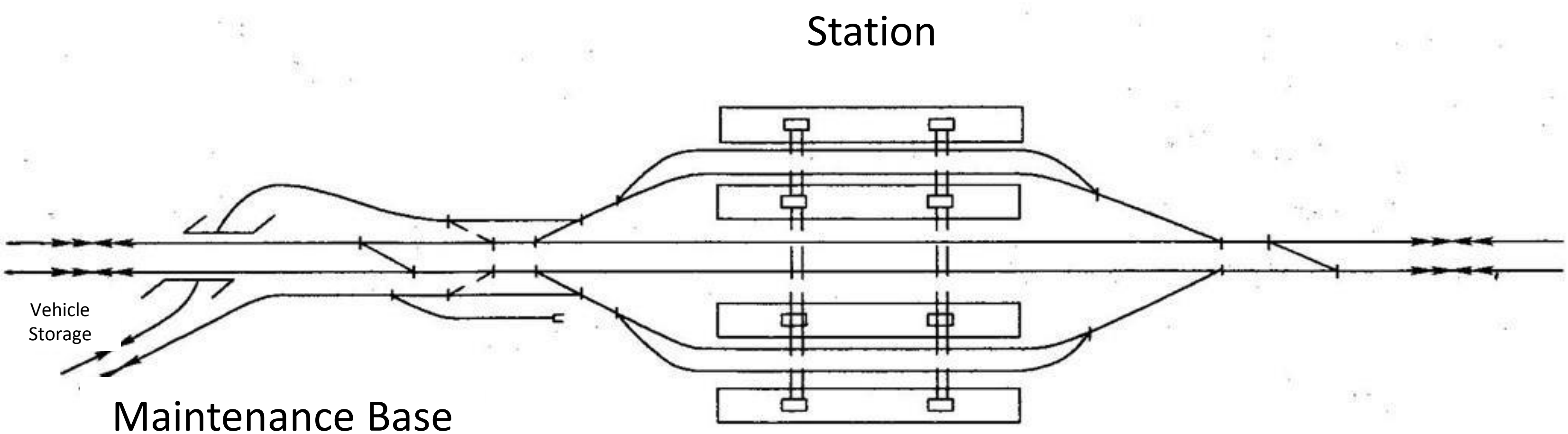
Symmetric Station



Island Station



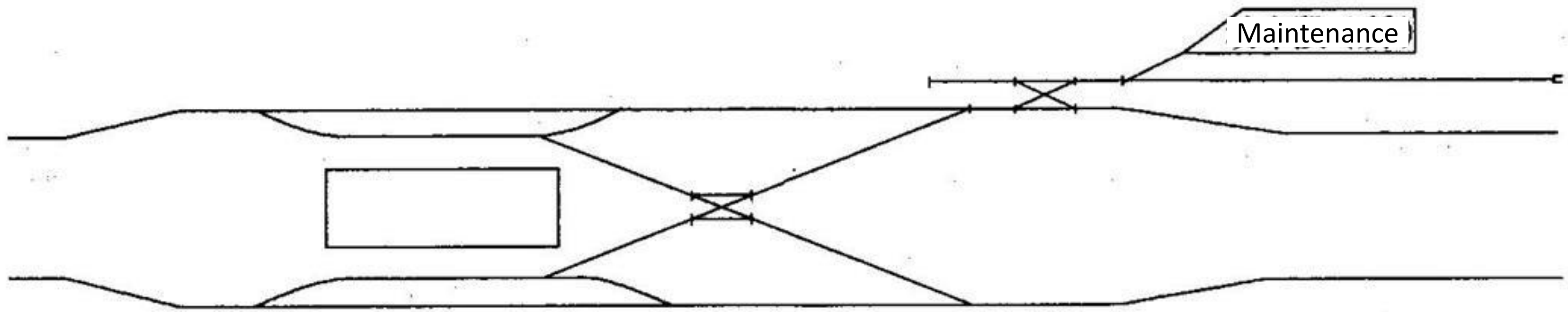
Station
3
I
II
4
Maintenance Base



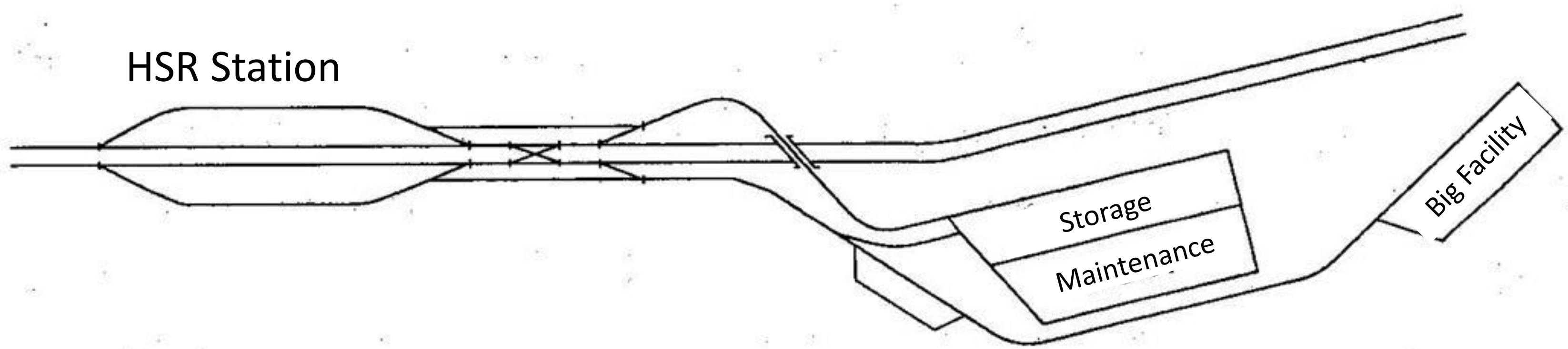
Station
Vehicle Storage
Maintenance Base

Station Technical Characteristics (cont.)

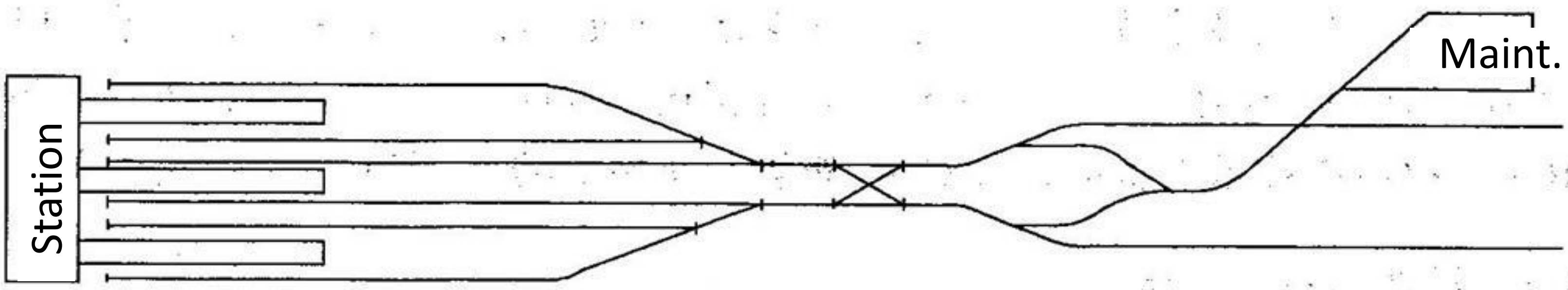
- Layouts for different types of stations
  - Intermediate stations
  - Intermediate stations with trains returning
  - Stations with departure and terminal



Main Track on the side



Through Main Track



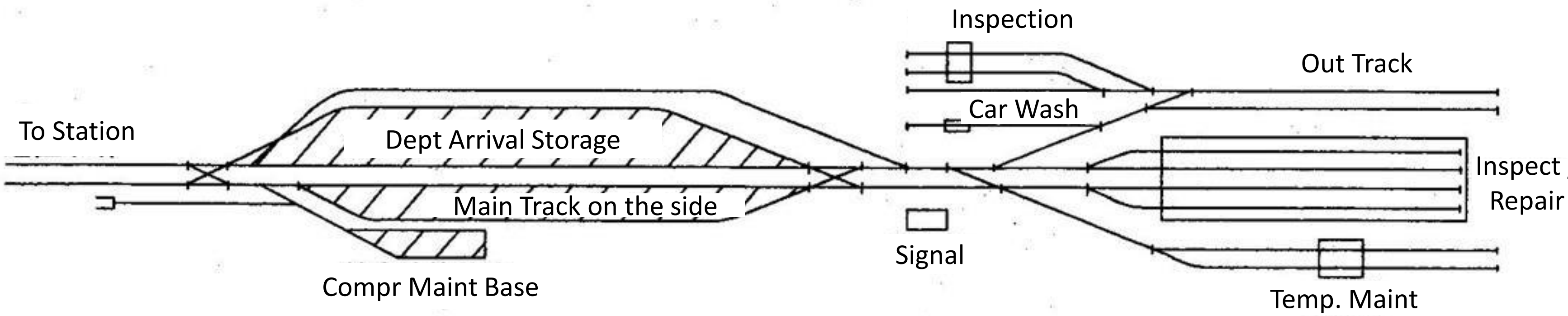
Terminal Station

HSR hub

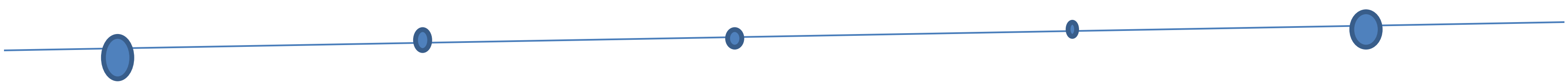
- Facility layouts
- Multimodal connectivity

Facilities in HSR hub

1. Rolling stock inspection and maintenance facilities
   - With different levels of facilities
2. System inspection and maintenance facilities
   - With different levels of facilities
3. Passenger stations
4. Train operation stations
5. Transfer facilities



Maintenance Yard



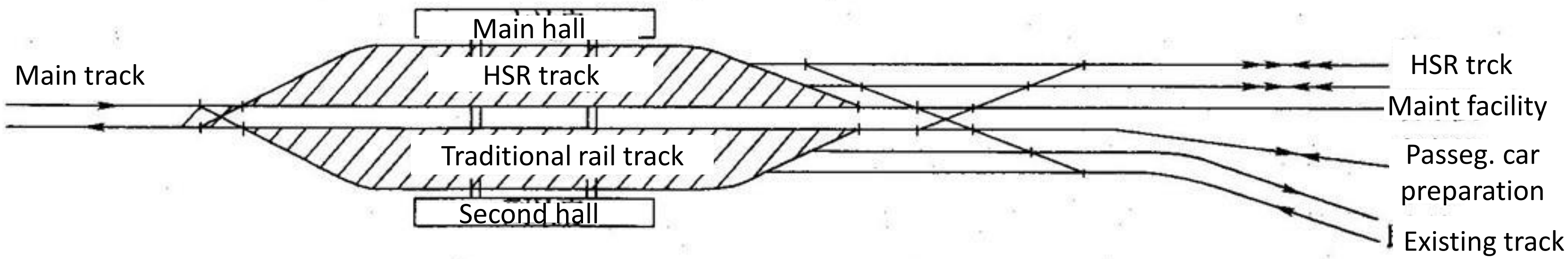

SACRAMENTO
STOCKTON
MODESTO
MERCED
MILLBRAE SFO
SAN JOSE
PENINSULA OPTION
GILROY
FRESNO
KINGS/TULARE REGIONAL STATION
BAKERSFIELD
PALMDALE TRANSPORTATION CENTER STATION
VICTORVILLE
EAST SAN GABRIEL VALLEY
SAN BERNARDINO
BURBANK AIRPORT STATION
ONTARIO AIRPORT
LOS ANGELES UNION STATION
NORWALK OPTION
RIVERSIDE
FULLERTON OPTION
ANAHEIM
CORONA
MURRIETA
ESCONDIDO
SAN DIEGO

HSR hub layout

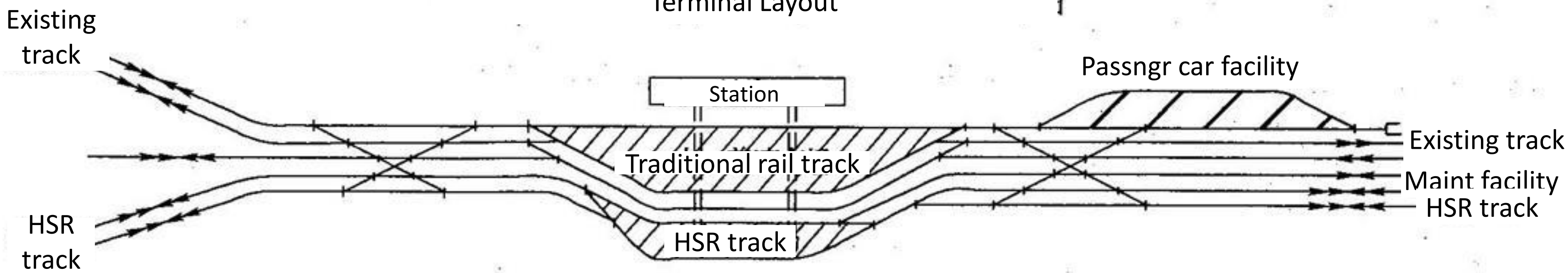
- HSR mixed with existing railroads
  - Consider whole railroad network
  - Consider city development
  - Consider connecting other modes of transportation

HSR hub layout (cont.)

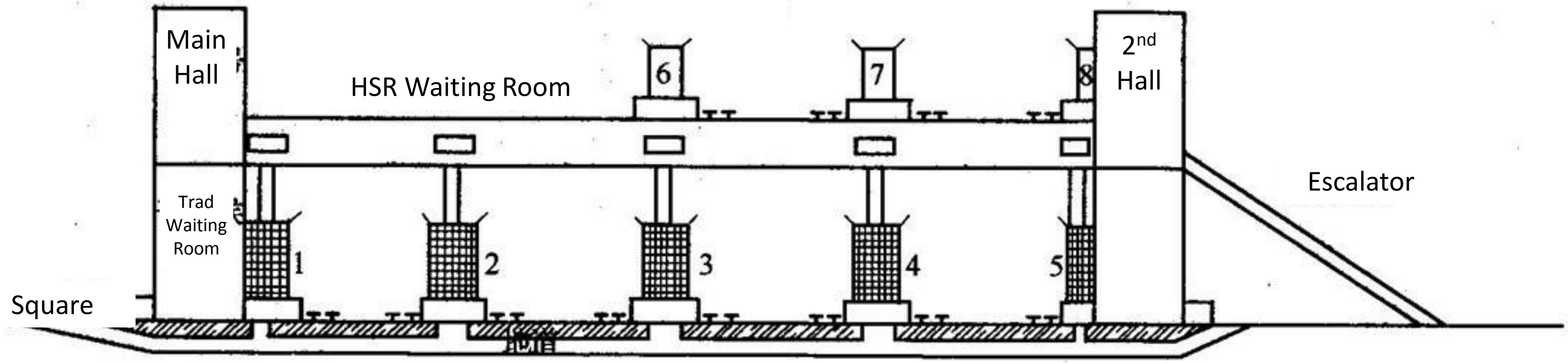
- The method to connect existing railroad
  - Connect at existing passenger station
    - Same level
      - Terminal station, same level
      - Passing through station, same level
    - Upper level
    - Lower level
  - Separate station
    - Connecting to existing passenger station
    - Not connecting to existing passenger station



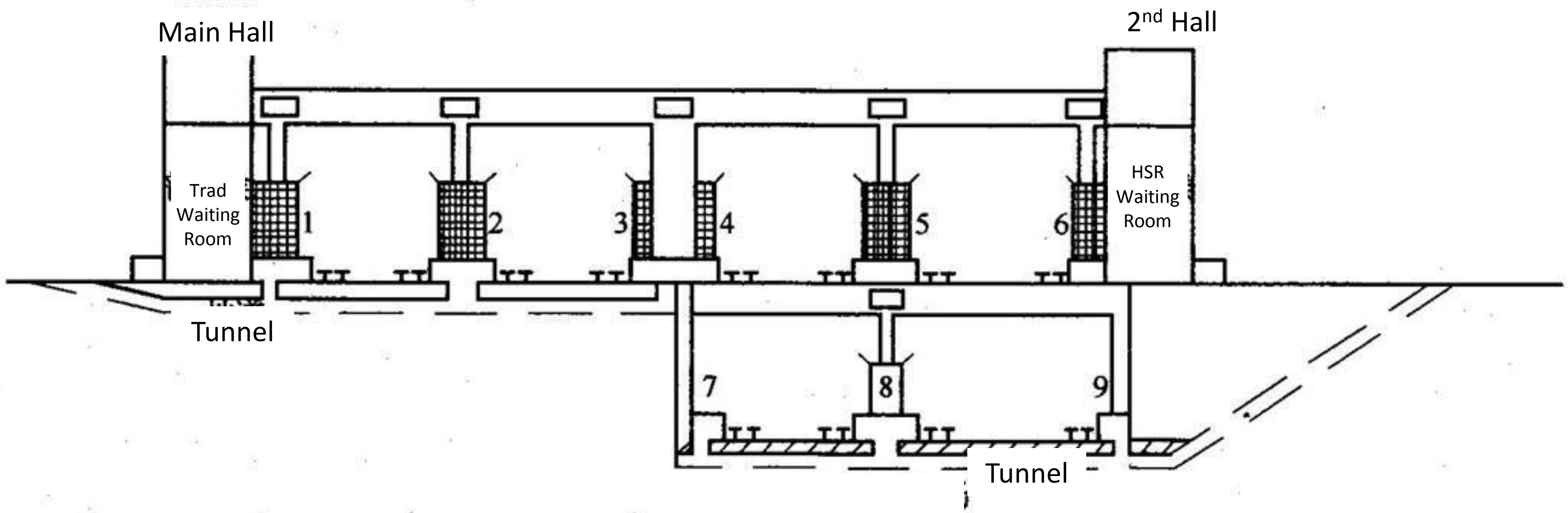
Terminal Layout



Through Layout



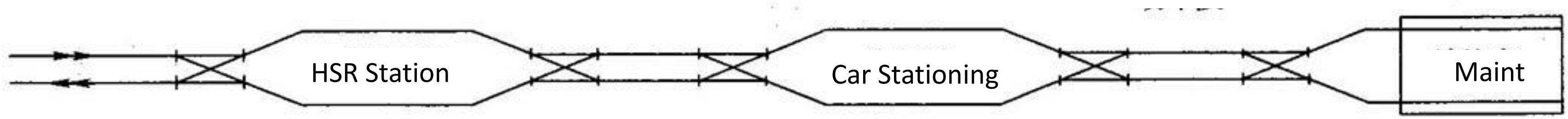
1～5— Traditional Trains 6～8— HSR trains

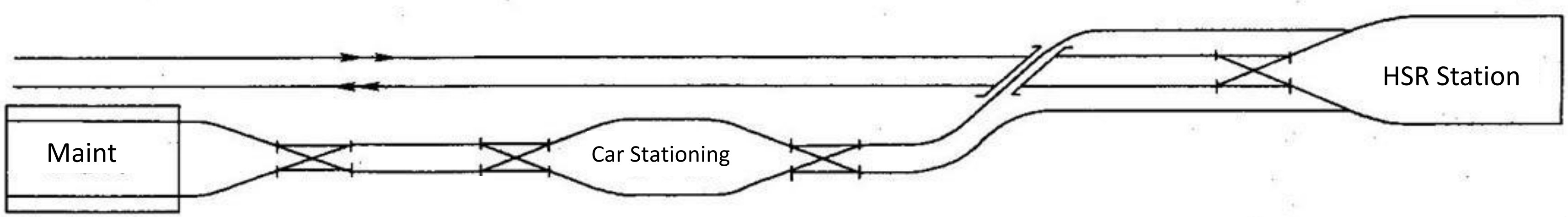


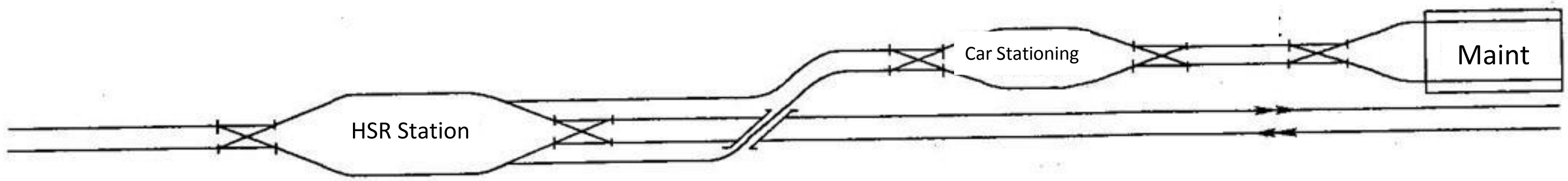
1～6— Traditional Trains ;7～9— HSR trains

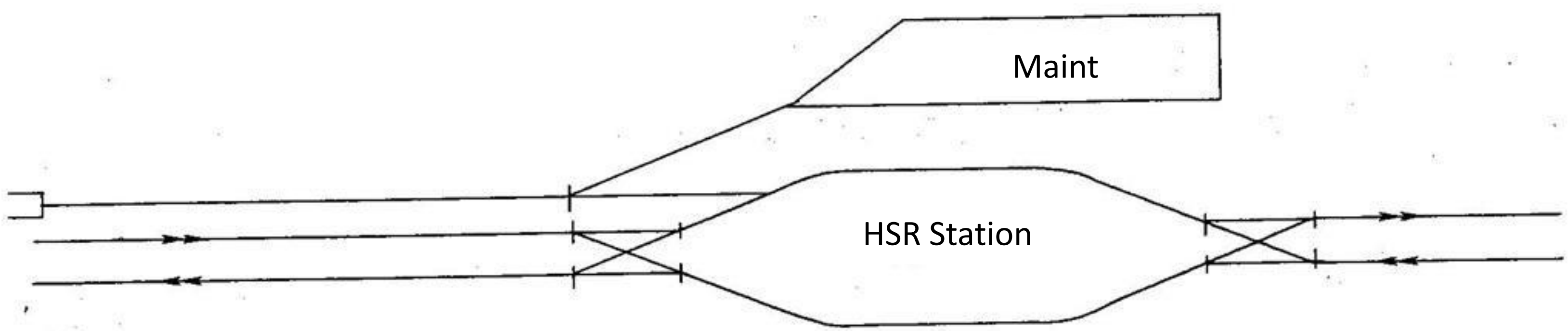
Location of minor maintenance facilities

- At terminal stations
- At passing through stations


HSR Station
Car Stationing
Maint


HSR Station
Maint
Car Stationing


Car Stationing
Maint
HSR Station


Maint
HSR Station

Location of major maintenance facilities

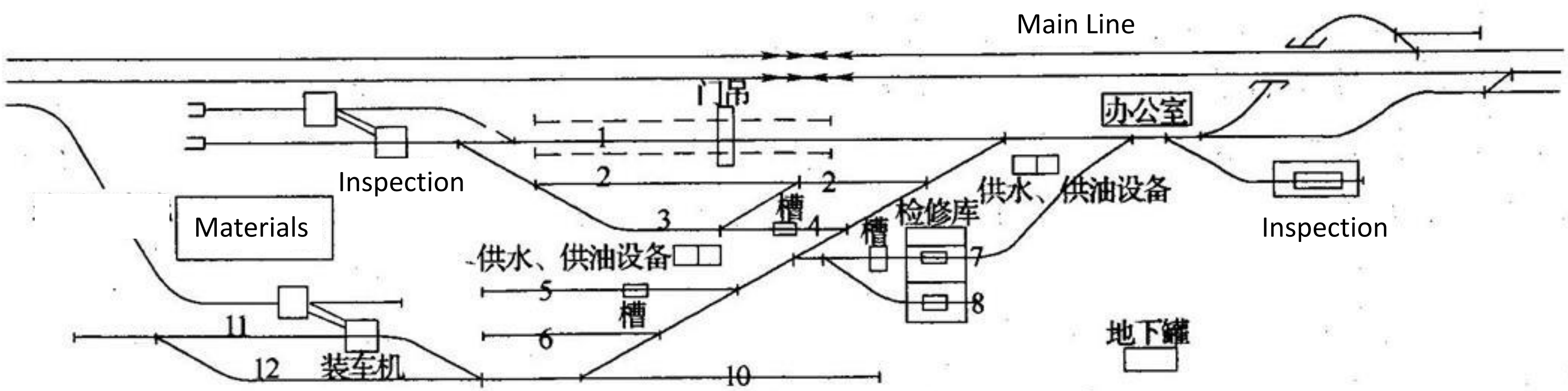


图 3.19　综合检修段设备布置图

Multimodal connection

- Capacity coordination
- Easy transfer
  - Subway, …
  - Door to door transfer (shuttle)
  - One card for multiple modes
  - Bring multiple modes to the front of stations

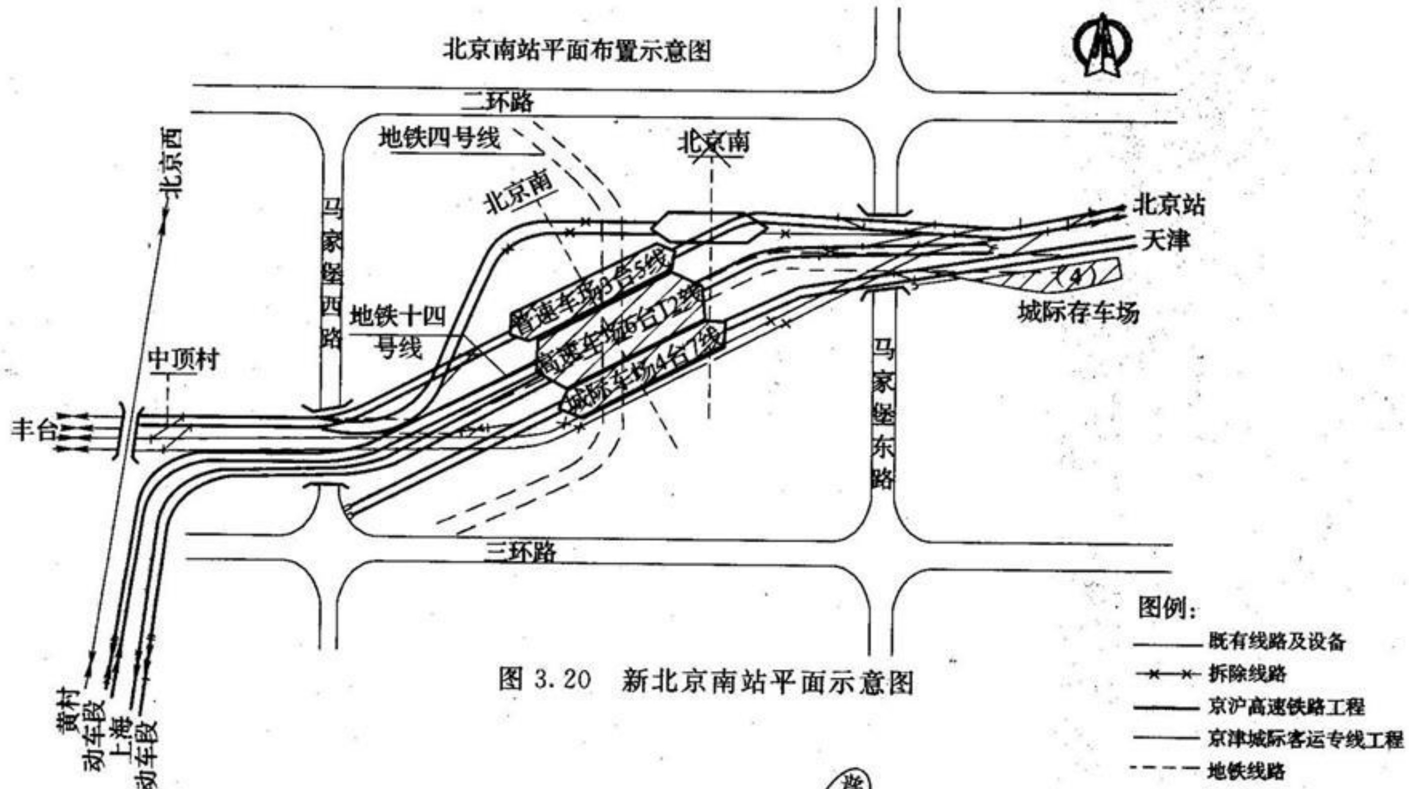


图 3.20　新北京南站平面示意图

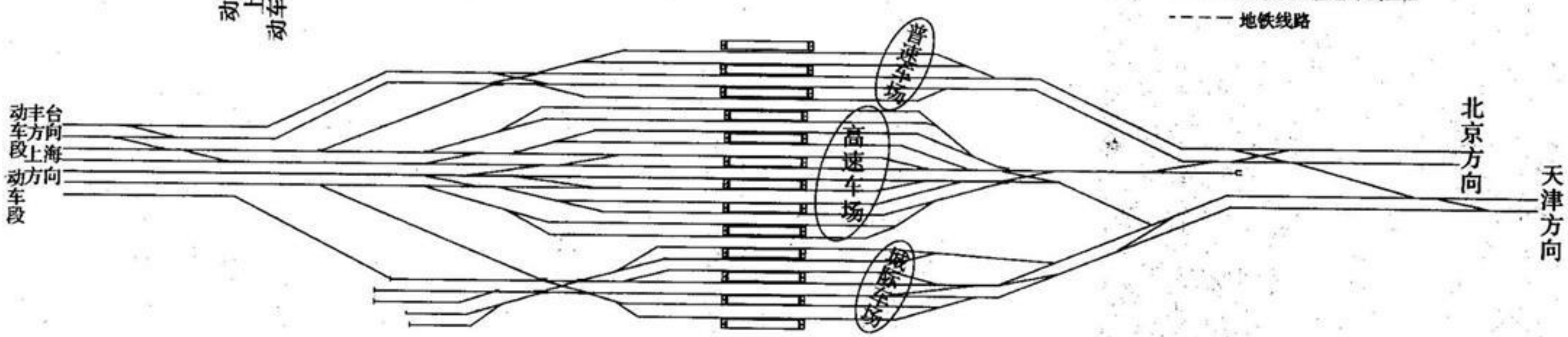
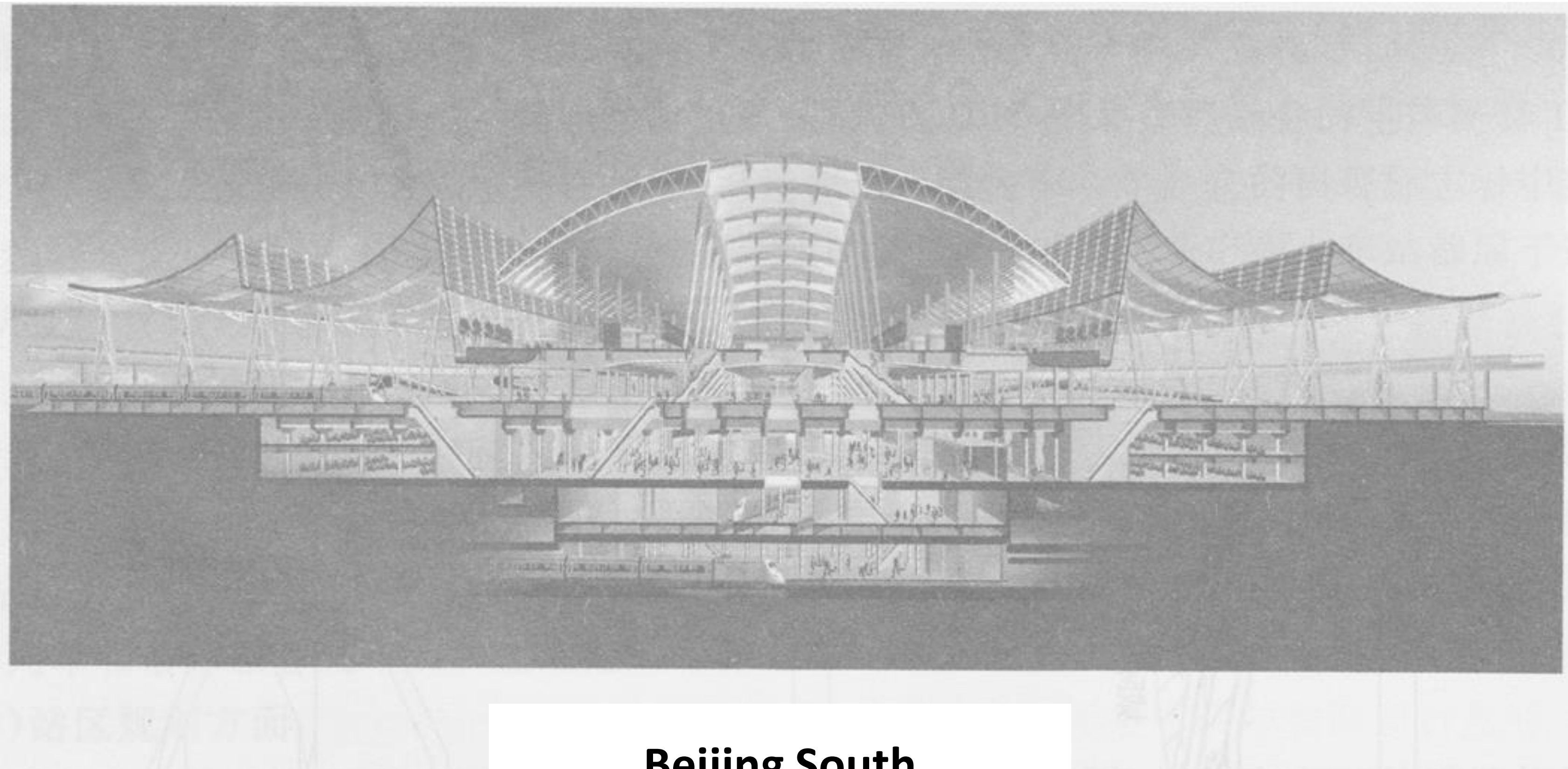


图 3.21　北京南站车场布置图



Beijing South

Traction Power Supply and Propulsion

Outline

- Traction power supply system
- Overhead contact line
- Pantograph
- Engine

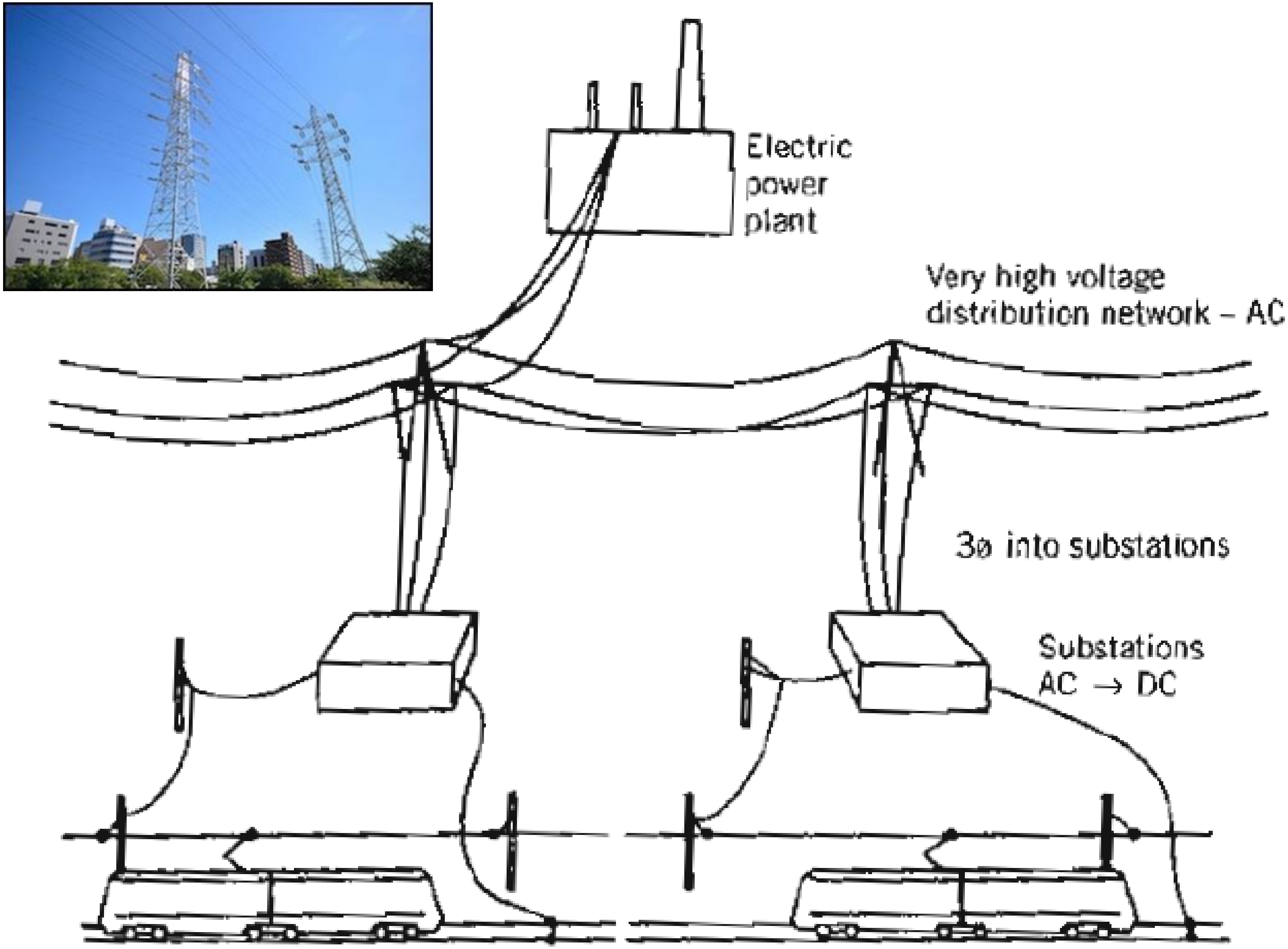
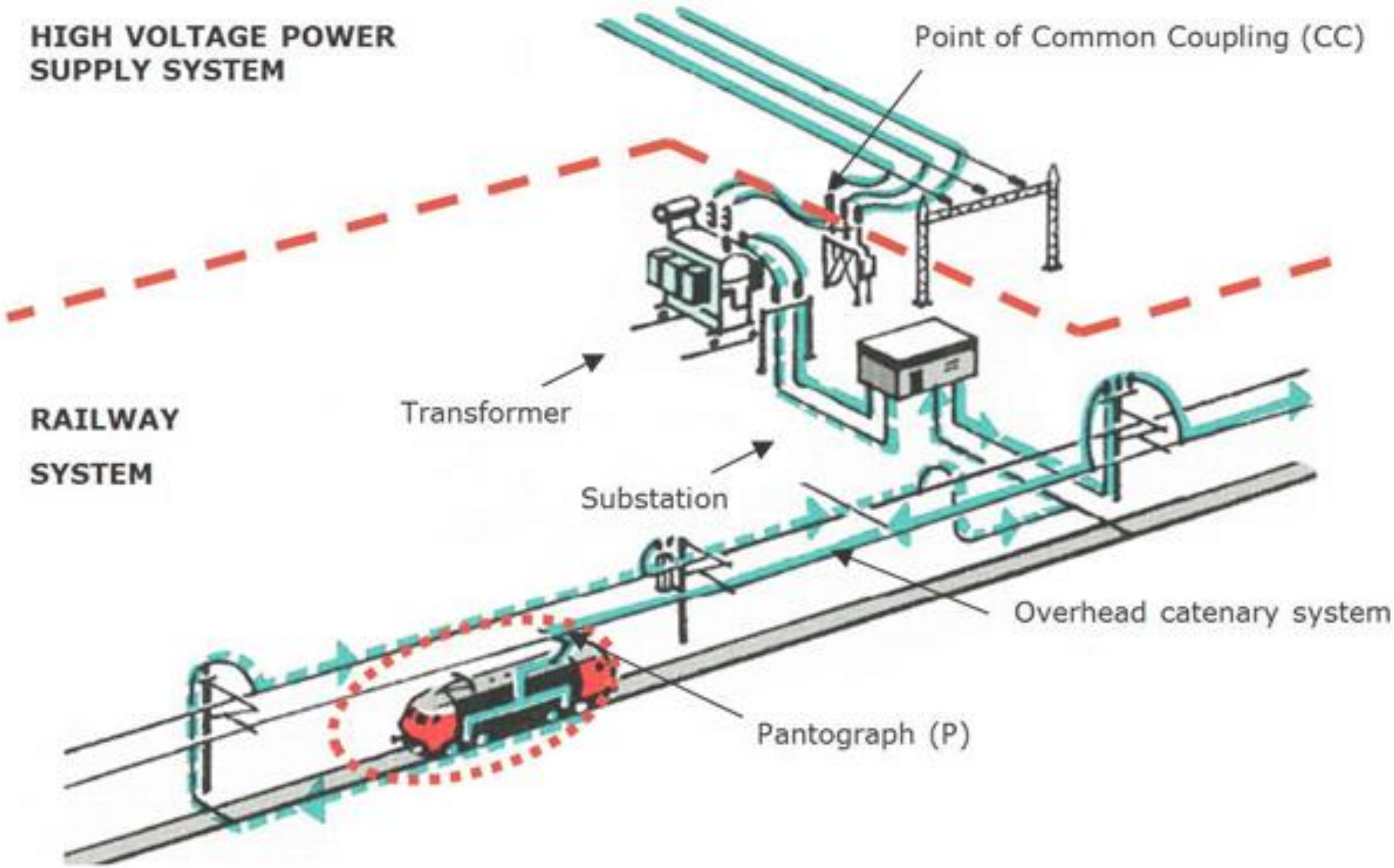
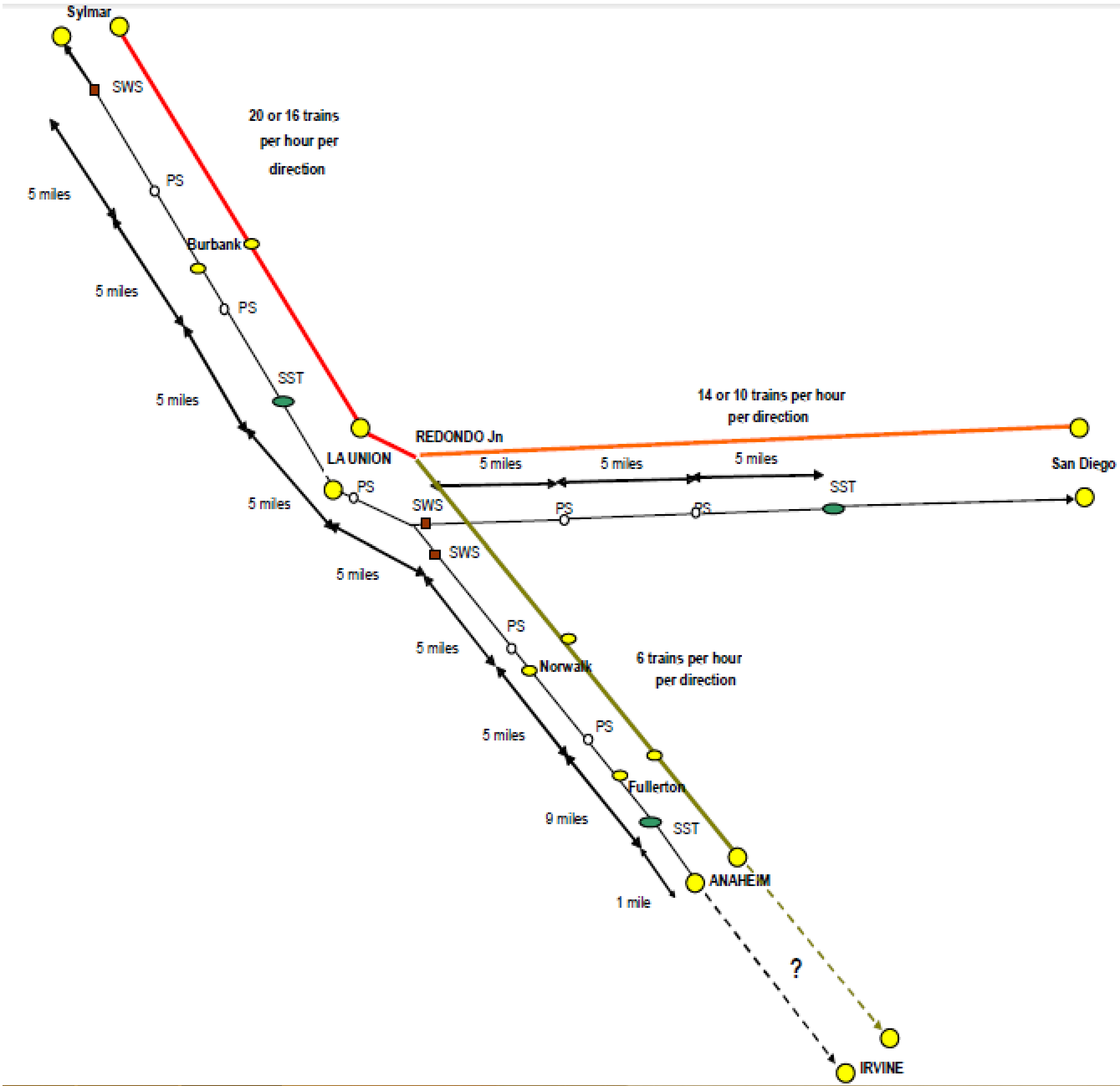


Figure 3.7 Power distribution system of a typical transit line



Sketch of system boundaries

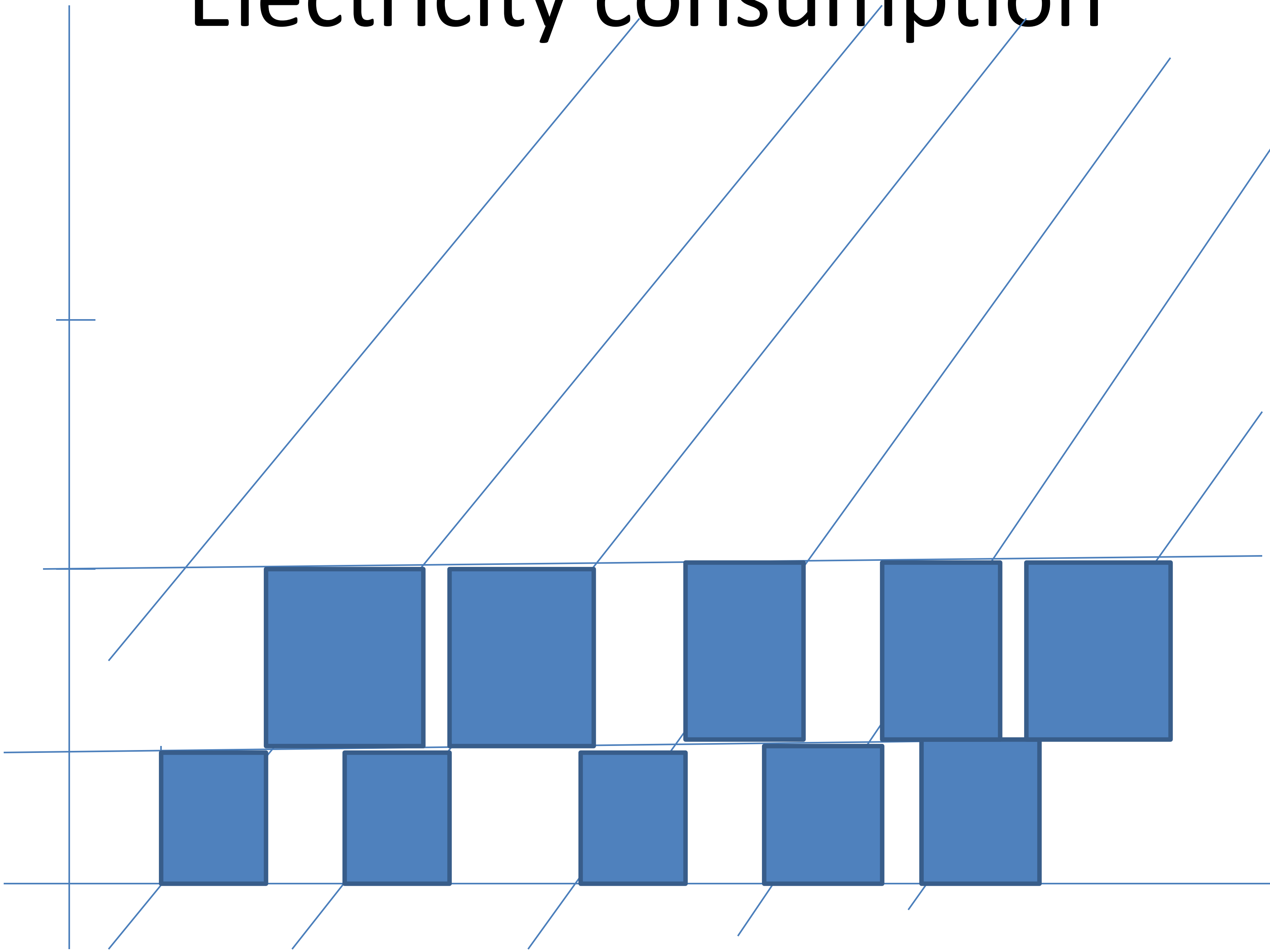
Figure 6: Feeding configuration between Los Angeles and Anaheim used for the traction power simulation


Sylmar
SWS
20 or 16 trains per hour per direction
5 miles
PS
Burbank
5 miles
PS
SST
5 miles
14 or 10 trains per hour per direction
REDONDO Jn
LA UNION
5 miles
5 miles
5 miles
San Diego
PS
SST
5 miles
SWS
PS
PS
SWS
5 miles
PS
5 miles
Norwalk
6 trains per hour per direction
PS
5 miles
Fullerton
9 miles
SST
ANAHEIM
1 mile
?
IRVINE

The system main components

- 2 x 25 kV Traction Power Supply Stations with a nominal output voltage of 50 kV.
- Paralleling Stations with 1 Autotransformer (2 autotransformers may be useful in special cases)
- Switching Stations (with Autotransformers)
- Phase break separation sections adjacent to traction power supply stations and switching stations.

Electricity consumption



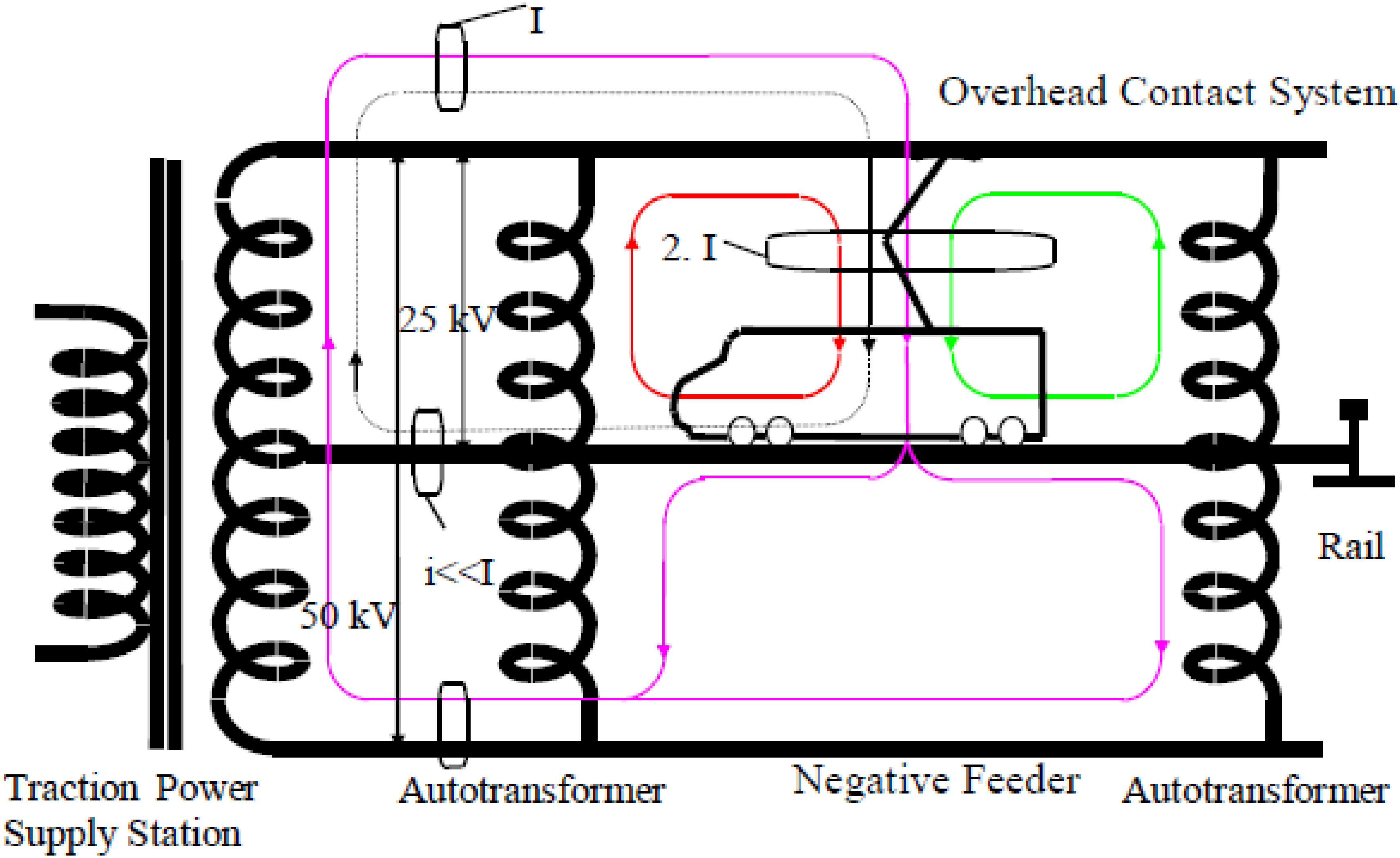
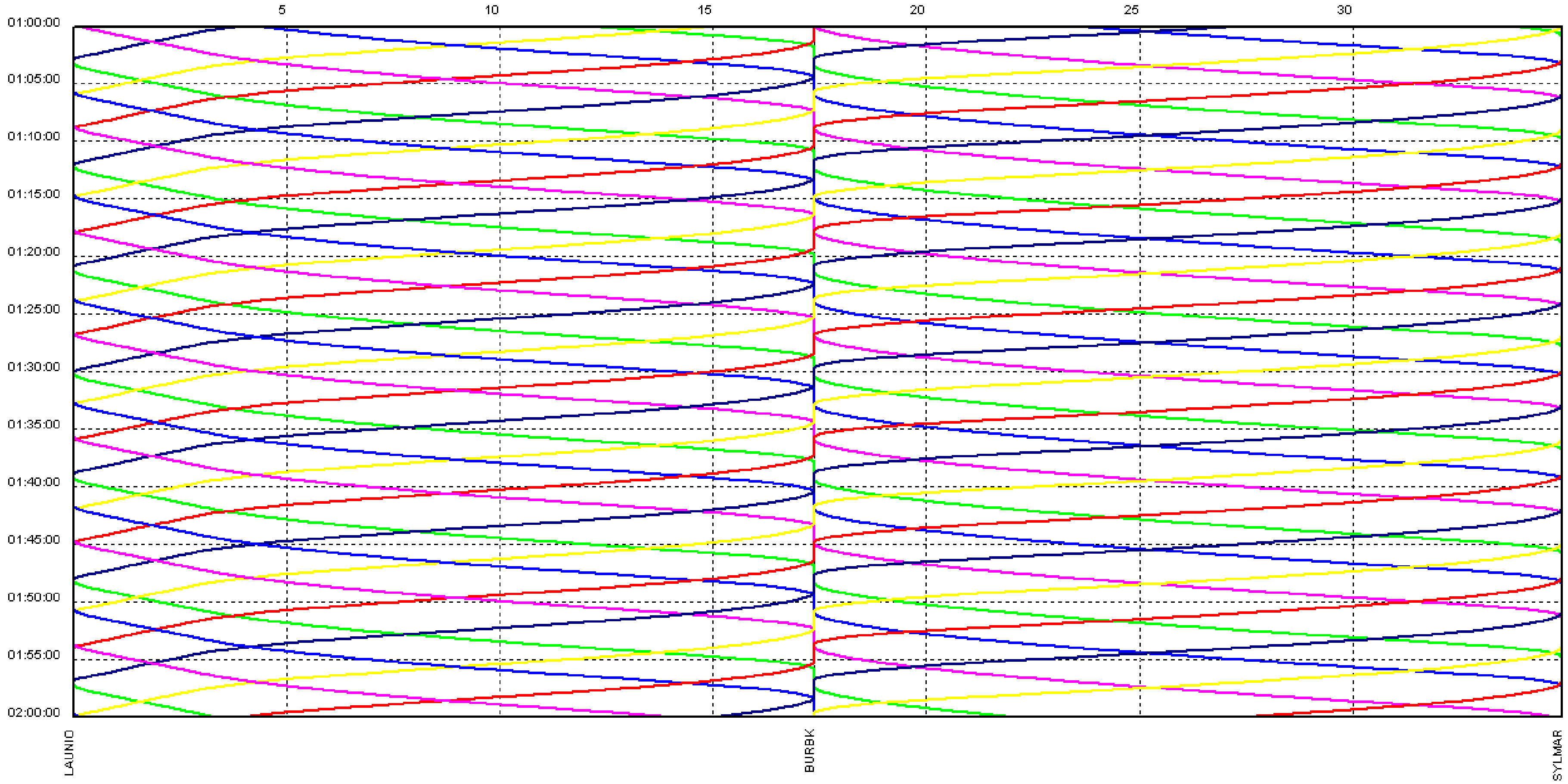


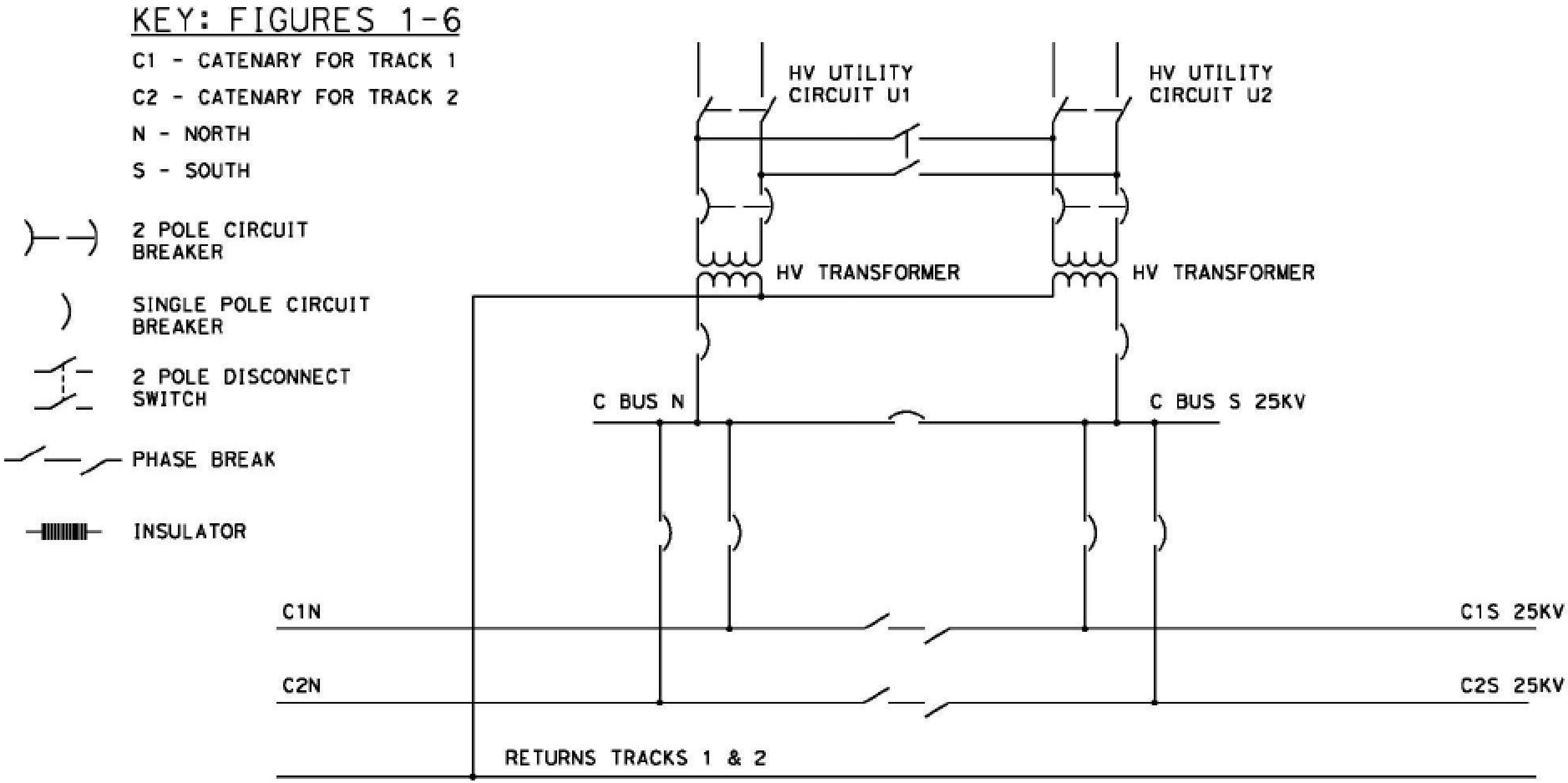
Figure 3: 2 x 25 kV principle


63
6

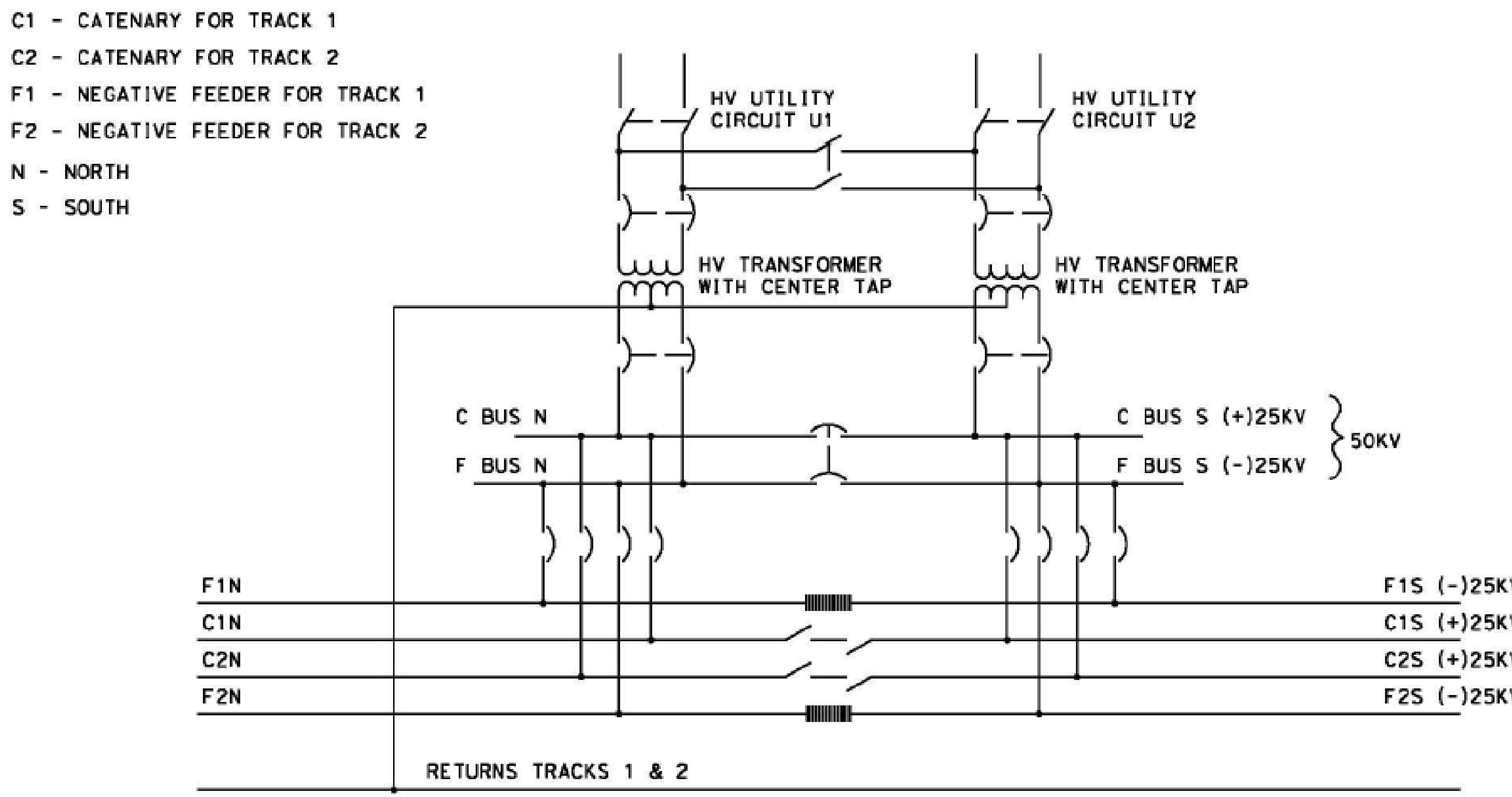
LA Union Station - Sylmar line with 3 min headway



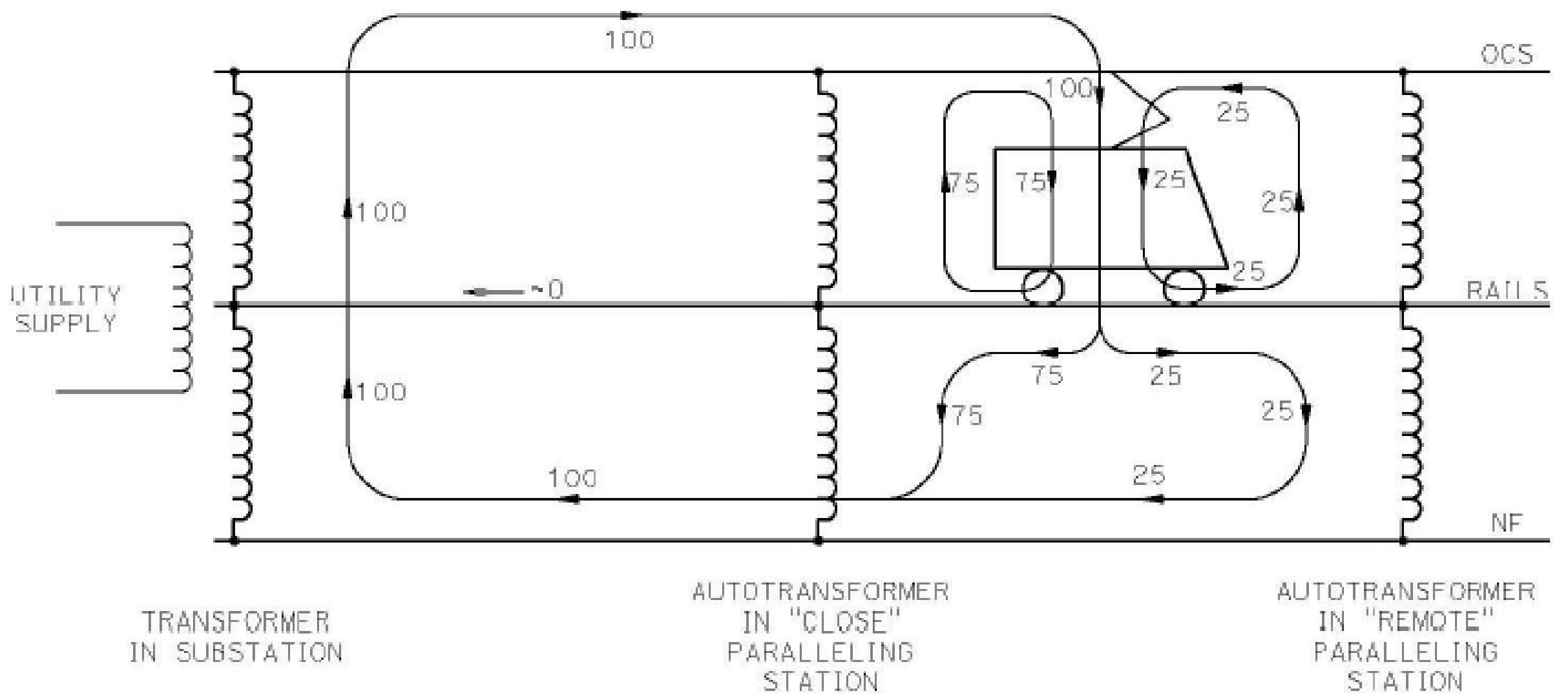
substation



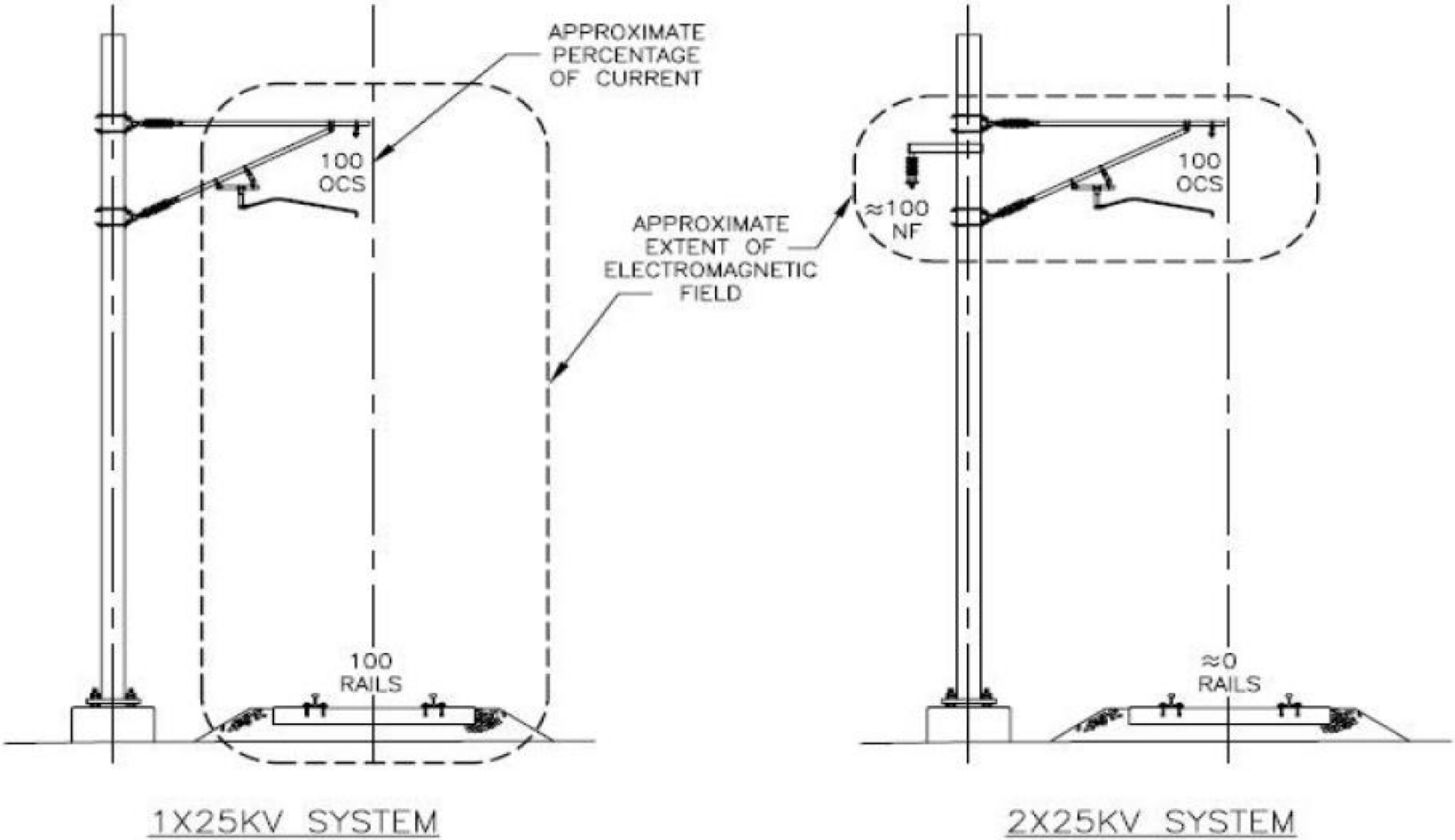
TRACTION POWER SUBSTATION WITH UTILITY SUPPLY - 1X25KV SYSTEM



TRACTION POWER SUBSTATION WITH UTILITY SUPPLY - 2X25KV AUTOTRANSFORMER FEED SYSTEM



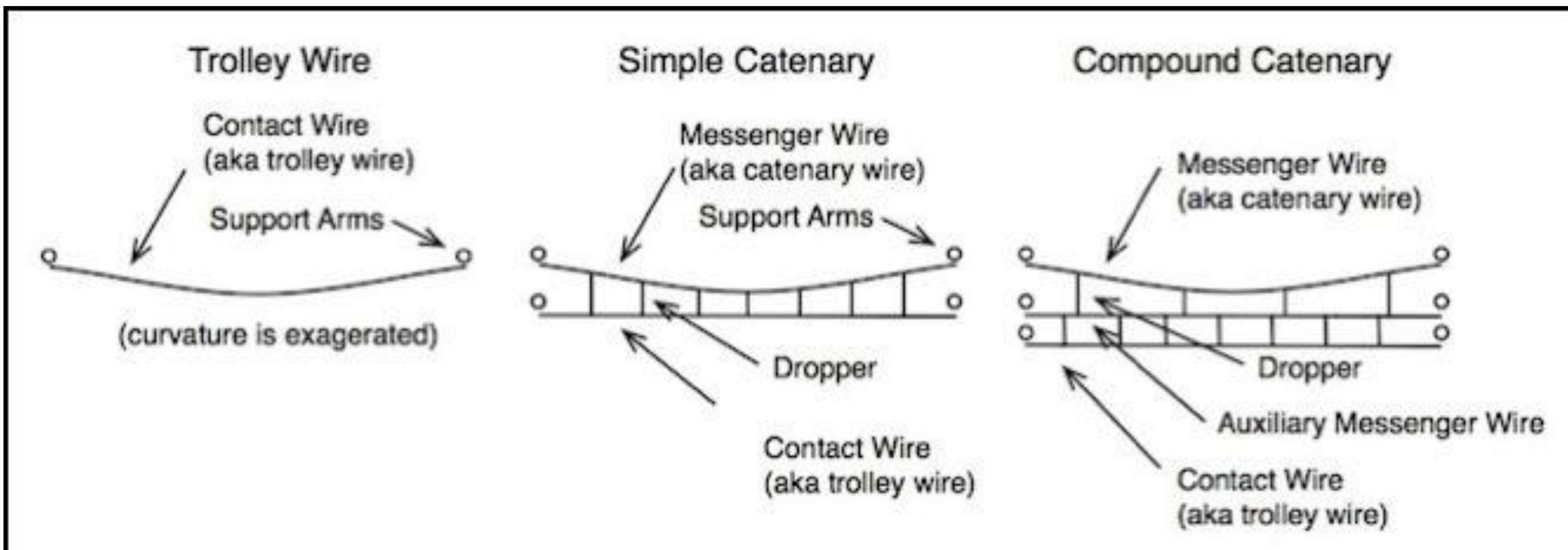
2X25KV AUTOTRANSFORMER FEED SYSTEM:
TYPICAL PROPORTIONAL CURRENT DISTRIBUTION FOR TRAIN LOAD OF 200A



SIMPLIFIED COMPARISON OF EXTENT
OF ELECTROMAGNETIC FIELD FOR
1X25KV AND 2X25KV SYSTEMS

Overhead contact line

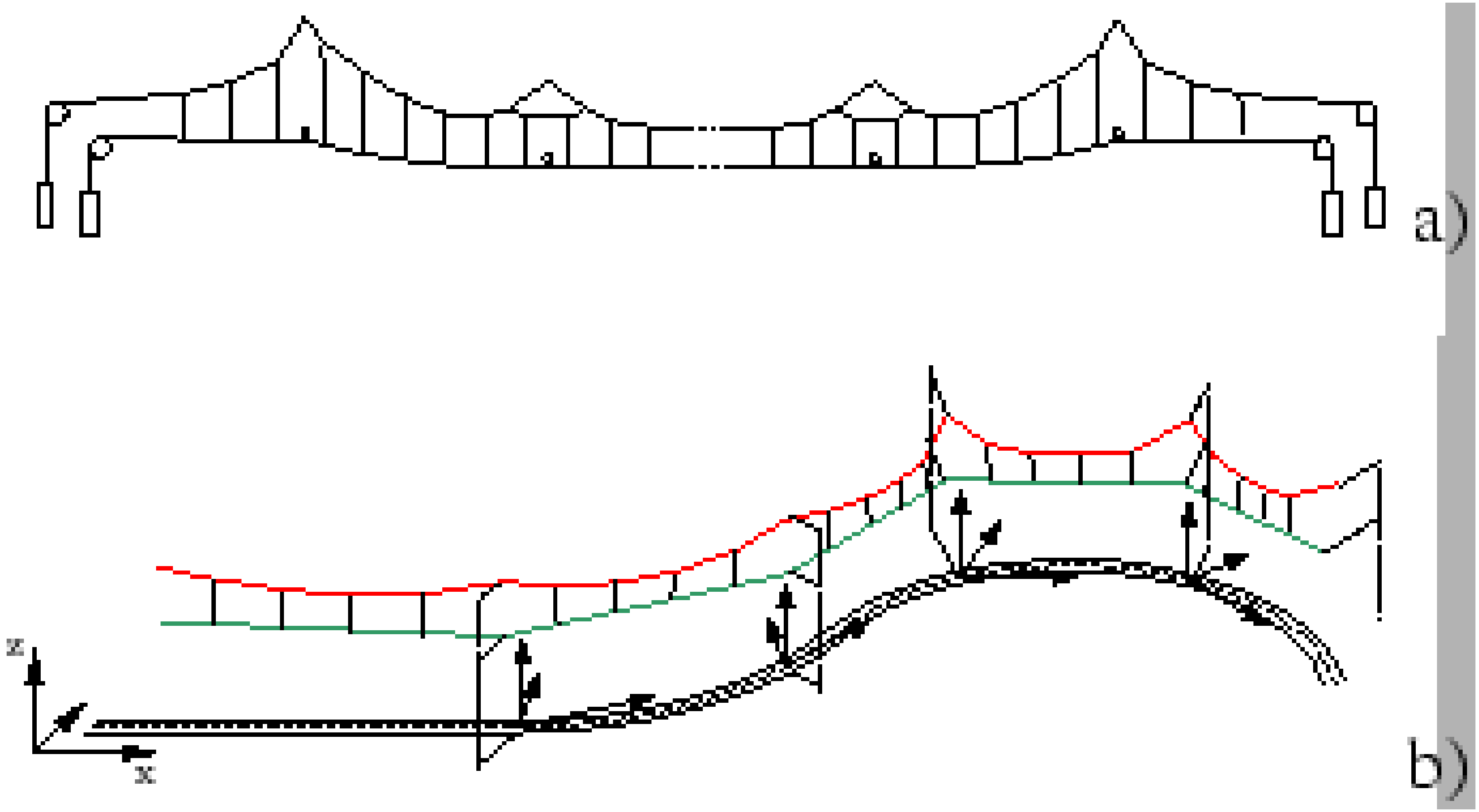
- https://www.youtube.com/watch?v=7ZiETnuidmc
- https://www.youtube.com/watch?v=kFPJ8eF9M2A



Tensioning

- auto-tensioning
- midpoint anchor

- http://en.wikipedia.org/wiki/Overhead_line



- http://www.mafy.lut.fi/EcmiNL/older/ecmi36/node16.html

Breaks

- Section break
- Neutral section (phase break)
- Dead section

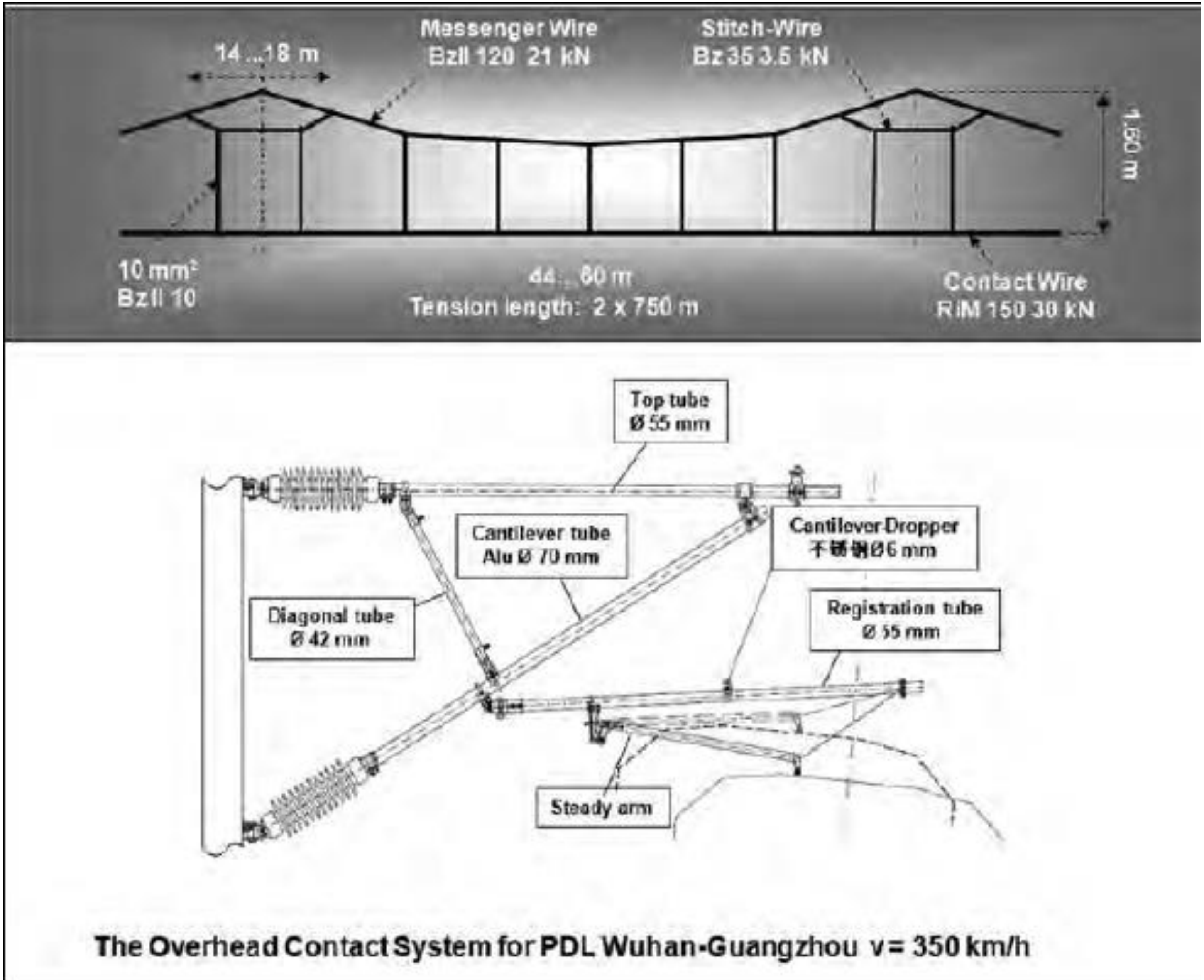
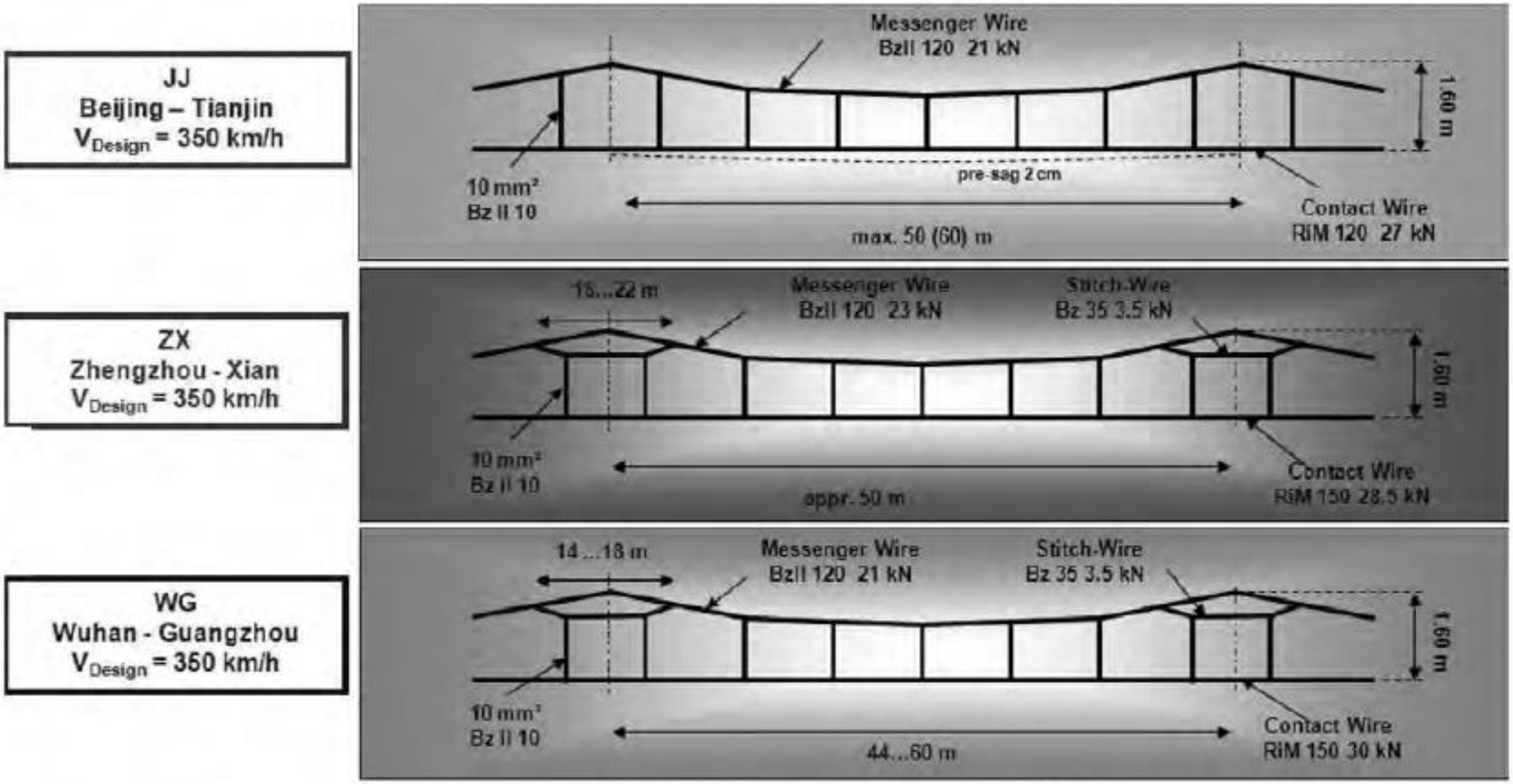


Figure 4: The overhead contact line system on the Wuhan-Guangzhou line



$$c = 3{,}6 * \sqrt{\frac{H_F}{m_F}}$$

$$v_{max} \leq 0{,}7 * c$$

Passenger Dedicated Line	Material and Cross-section of contact wire	Force in contact wire in kN	Wave propagation velocity c	Max. operation speed $v_{max}=0{,}7 \cdot c$
Beijing-Tianjin	CuMg 120	27,0 kN	572 km/h	400 km/h
Zhengzhou-Xian	CuMg 150	28,5 kN	525 km/h	368 km/h
Wuhan-Guangzhou	CuMg 150	30,0 kN	540 km/h	378 km/h

Figure 5: Chinese high-speed overhead contact lines (concepts)

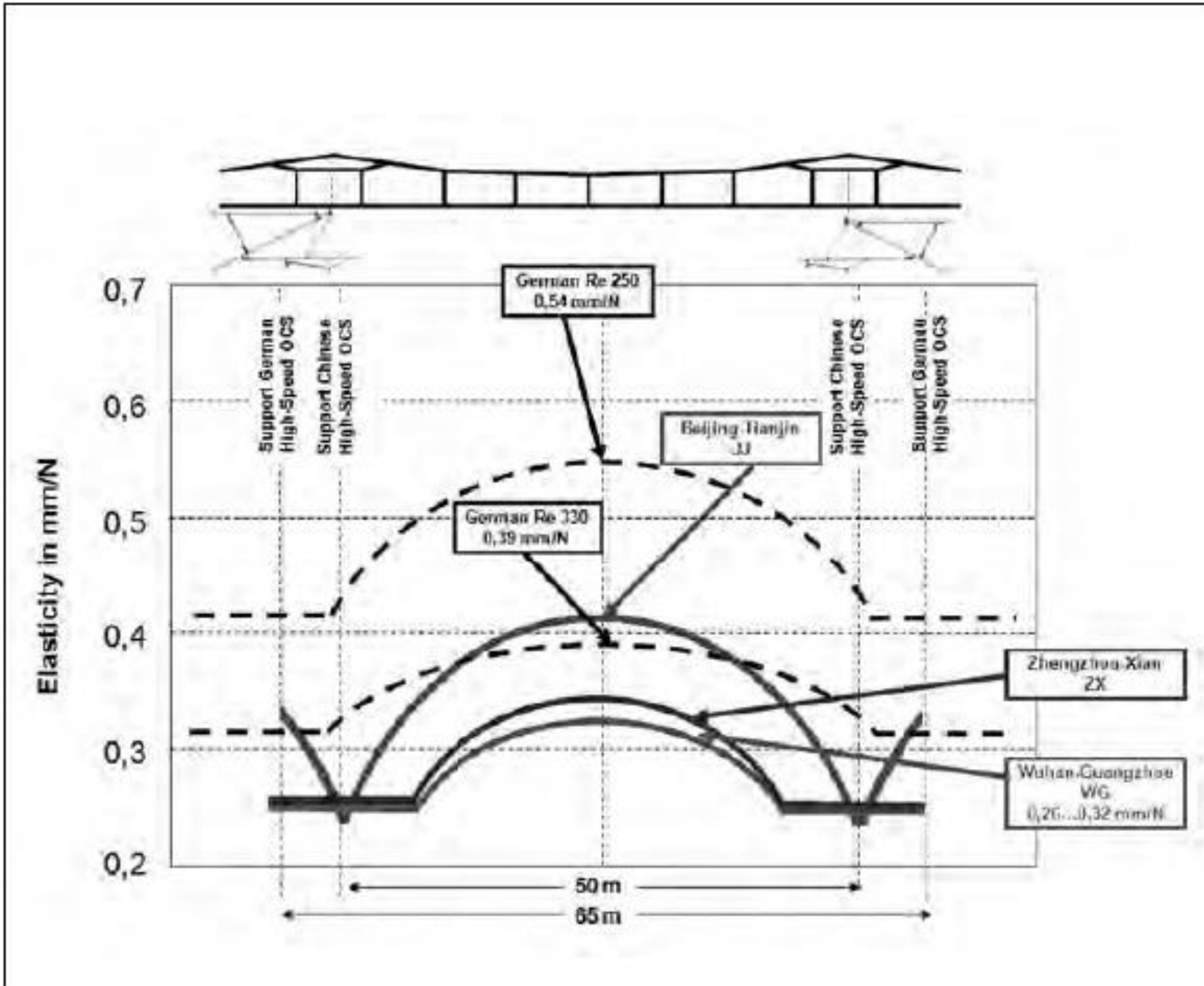


Figure 6: Elasticities in the high-speed overhead contact lines

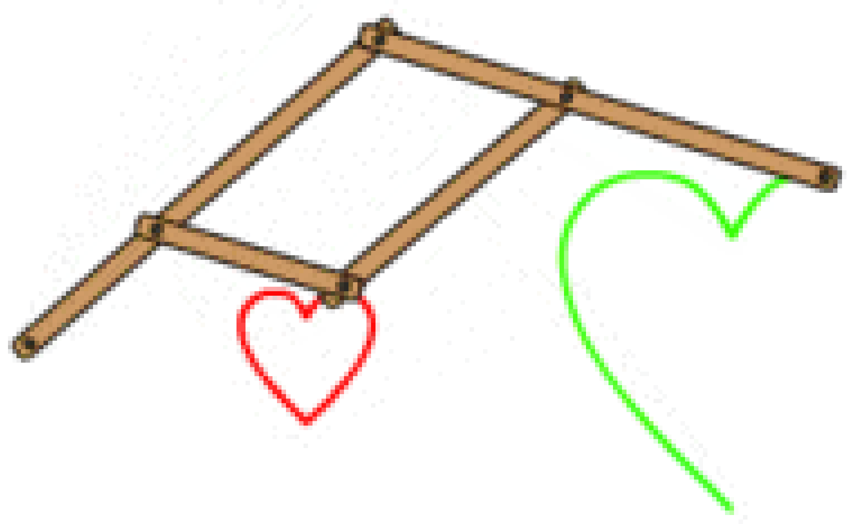
Receiving Electricity

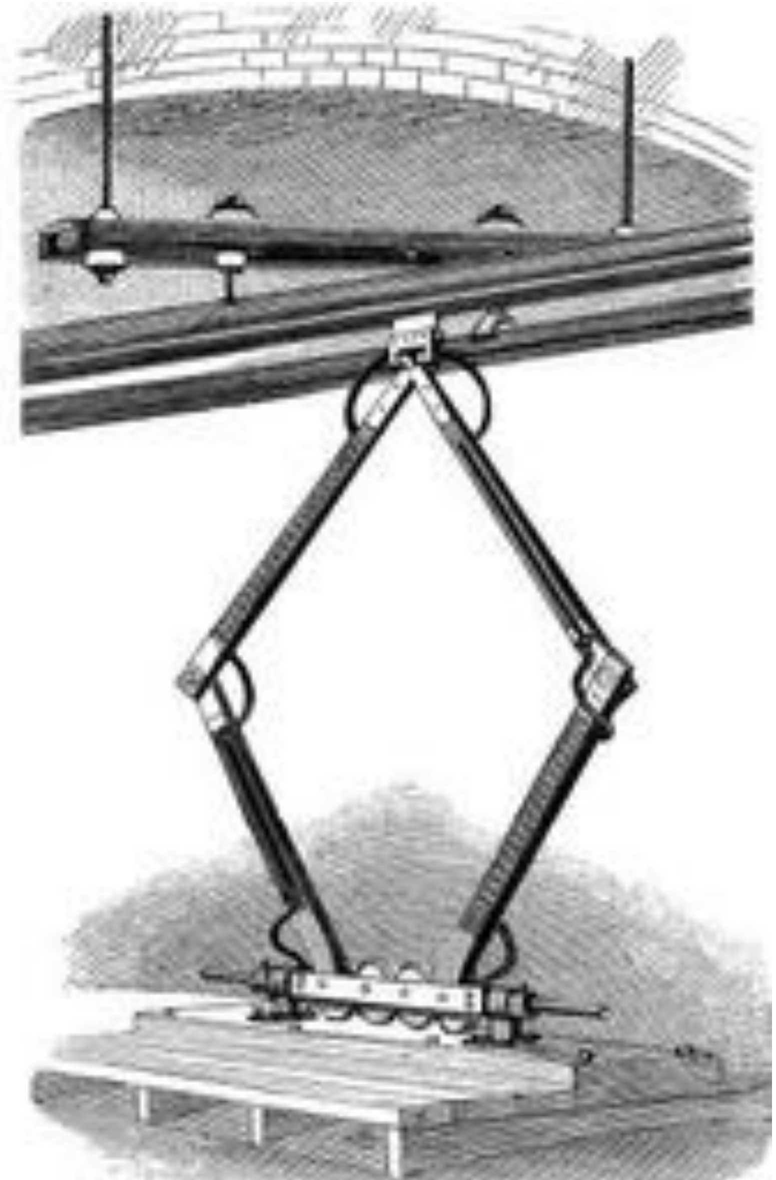
$$c = \sqrt{\frac{T}{\rho}}$$

- C: wave speed, m/s
- T: wire tension, N
- P: wire density, kg/m

Pantograph

- http://en.wikipedia.org/wiki/Pantograph

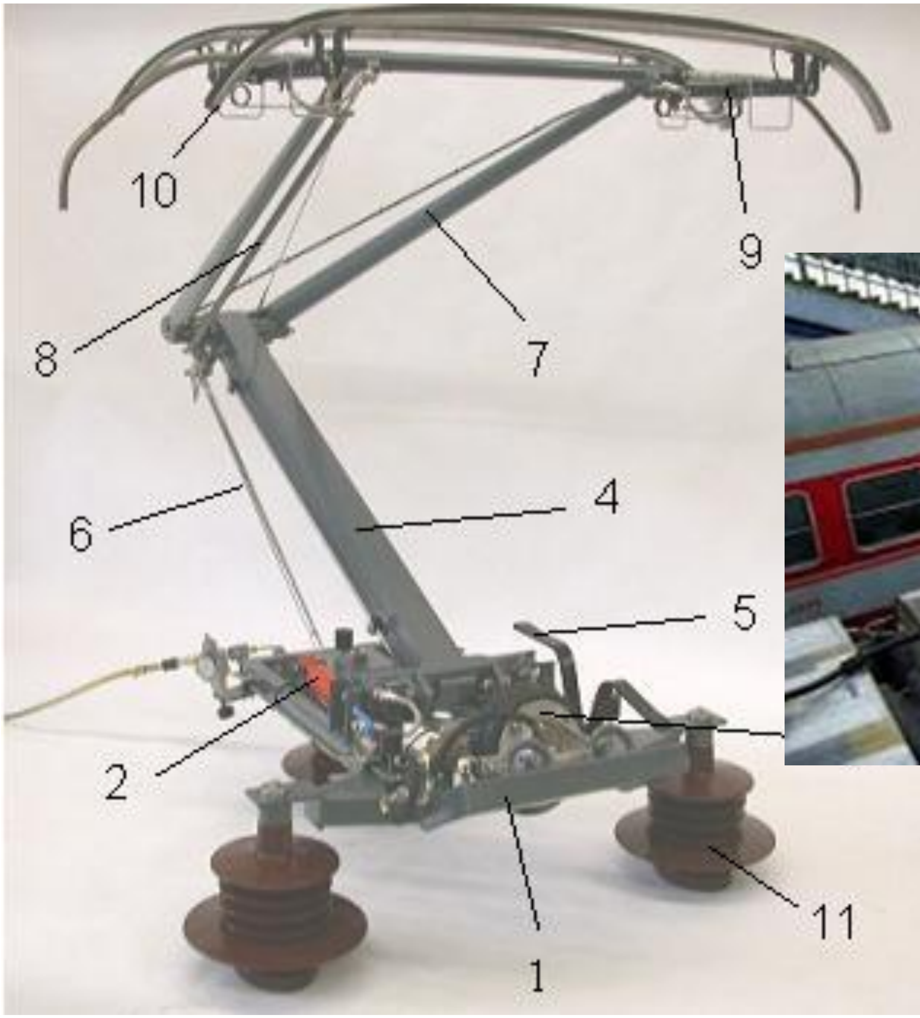




- http://en.wikipedia.org/wiki/Pant

- The (asymmetrical) 'Z'-shaped pantograph of the electrical pickup on the Berlin Straßenbahn. This pantograph uses a single-arm design

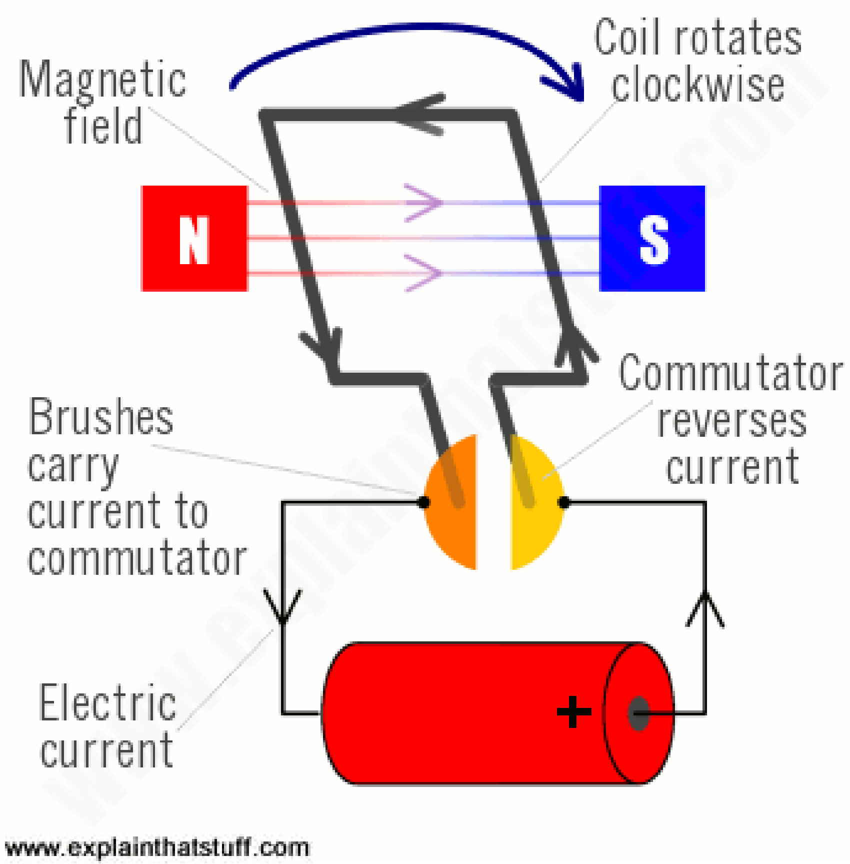
Pantograph (CRH DAS250)



Design requirement for HSR pantograph

- The sliding plate and wire have appropriate contact force
- Reduce the weight of the mobile of pantograph
- Reduce aerodynamics on the contact force between sliding plate and wire
- Sliding plate should be strong
- Reduce noise caused by pantograph

How does an ordinary DC motor work?



- http://www.explainthatstuff.com/induction-motors.html

DC Motor

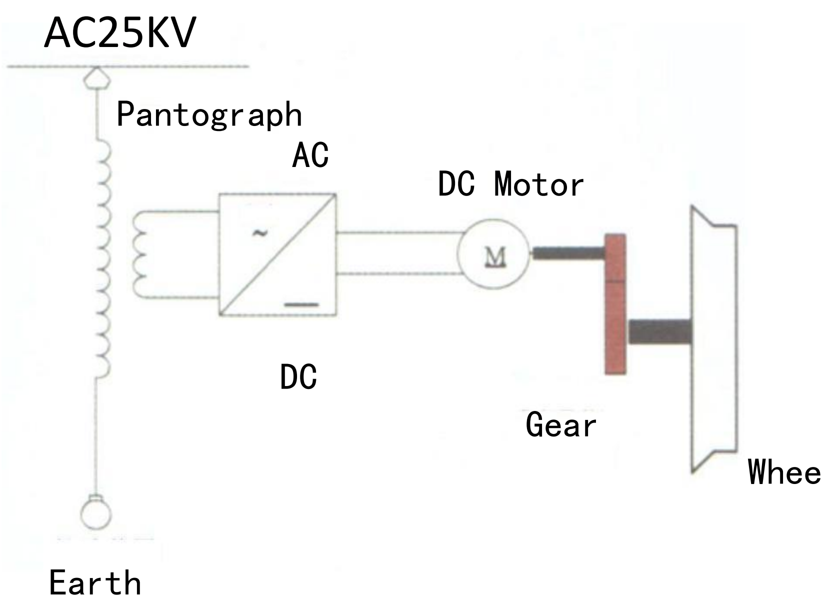
DC Motor, How it works?

https://www.youtube.com/watch?v=LAtPHANEfQo

dc motor

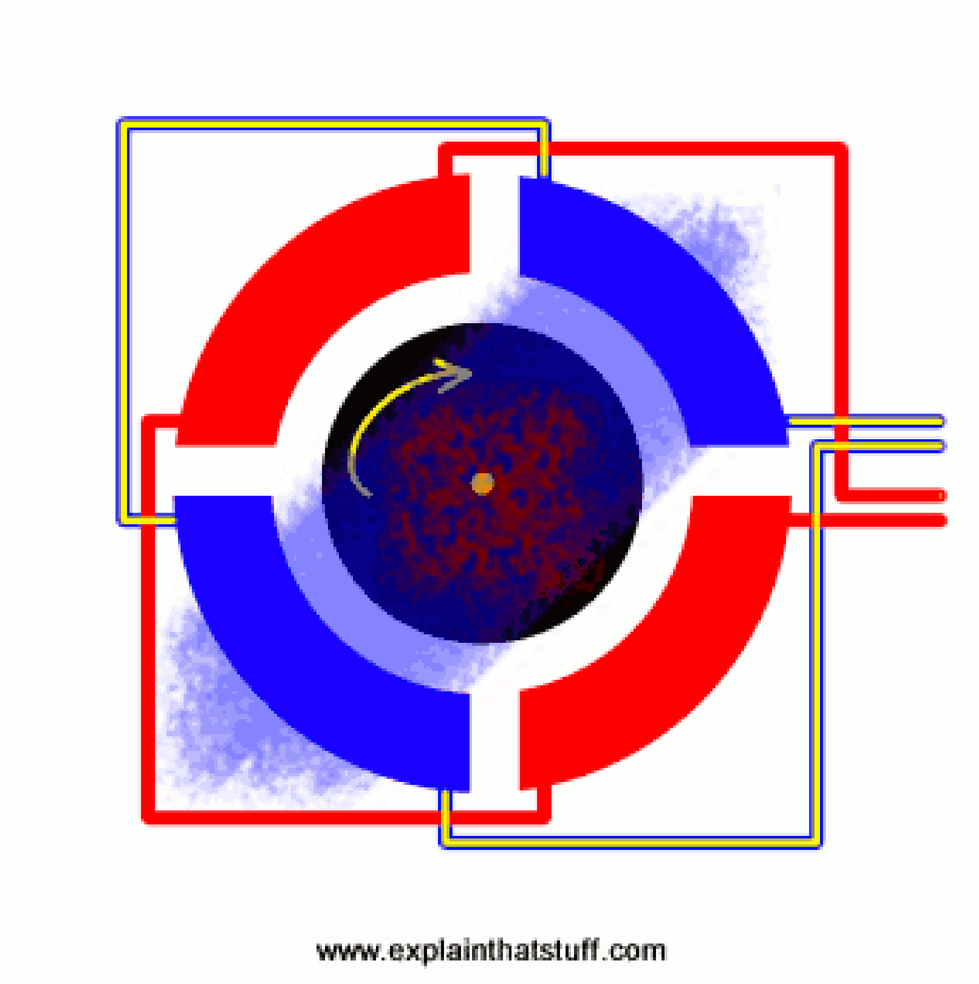
https://www.youtube.com/watch?v=fWyzPdyCAzU

DC Motor



- Easy to control the speed
- Hard to maintain the commutator and brush

How does an AC motor work?



- http://www.explainthatstuff.com/induction-motors.html

AC Motor

Rotating Magnetic Field

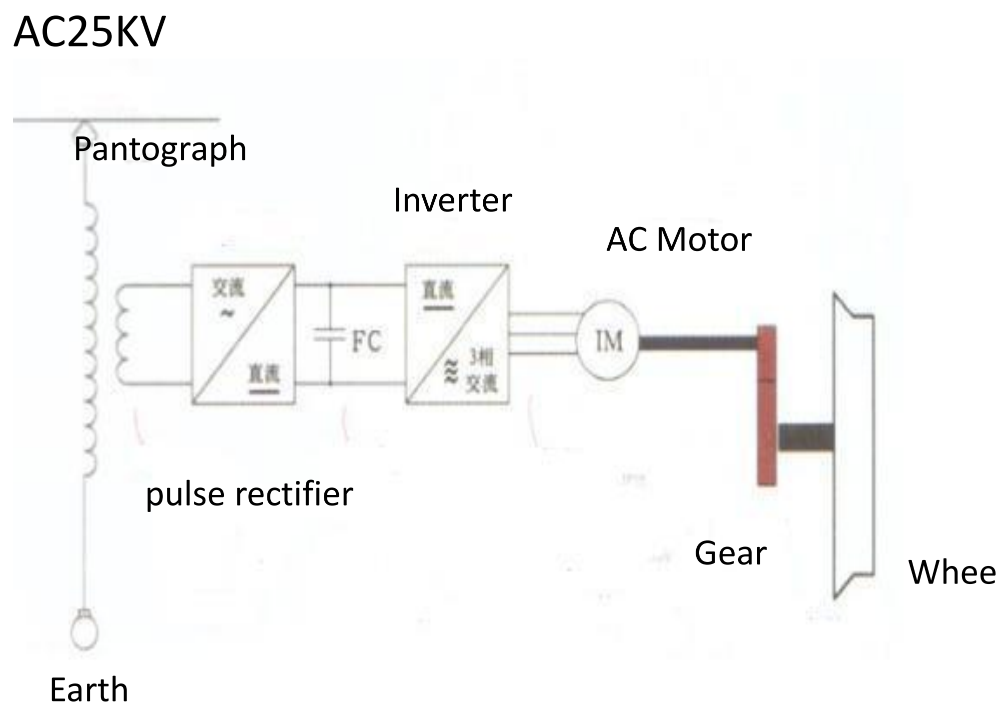
https://www.youtube.com/watch?v=SiZ-mak4h4s

Rotating Magnetic Field & Synchronous Speed

https://www.youtube.com/watch?v=8XF-11MQGQ0

Working of Synchronous Motor

https://www.youtube.com/watch?v=Vk2jDXxZIhs


AC25KV
Pantograph
Inverter
AC Motor
交流
~
直流
FC
直流
3相
交流
IM
pulse rectifier
Gear
Wheel
Earth

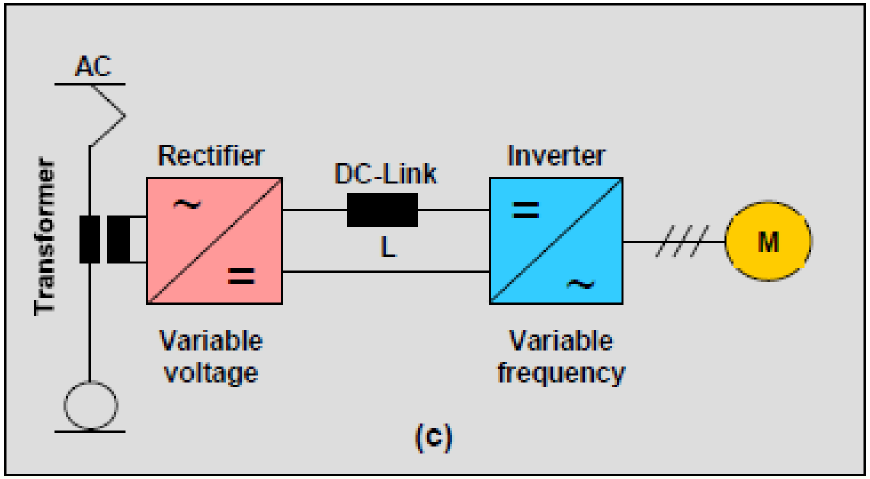
AC motor is better

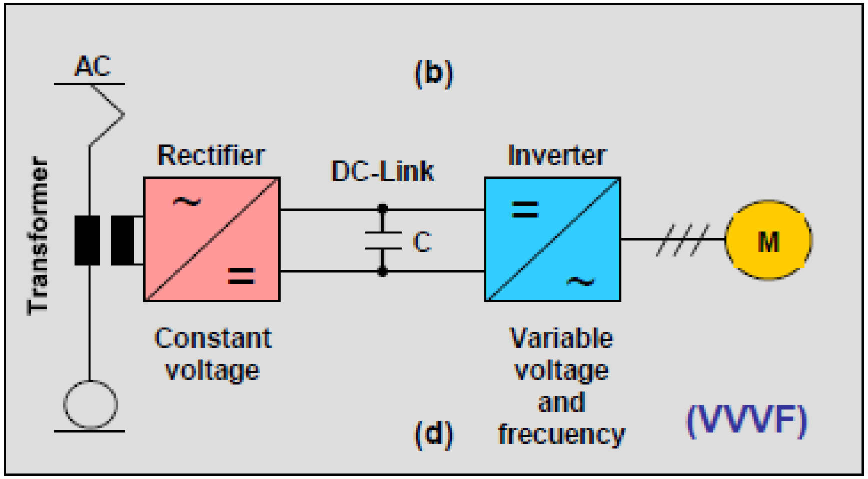
- Structure is simple, no commutator, no brush, no part to deteriorate
- System modular based, more reliable, easy to maintain
- Easy to switch to electricity regeneration, no change on the circuit, no contact electronics
- Any changes can be made through software, not hardware

AC motor is better (cont.)

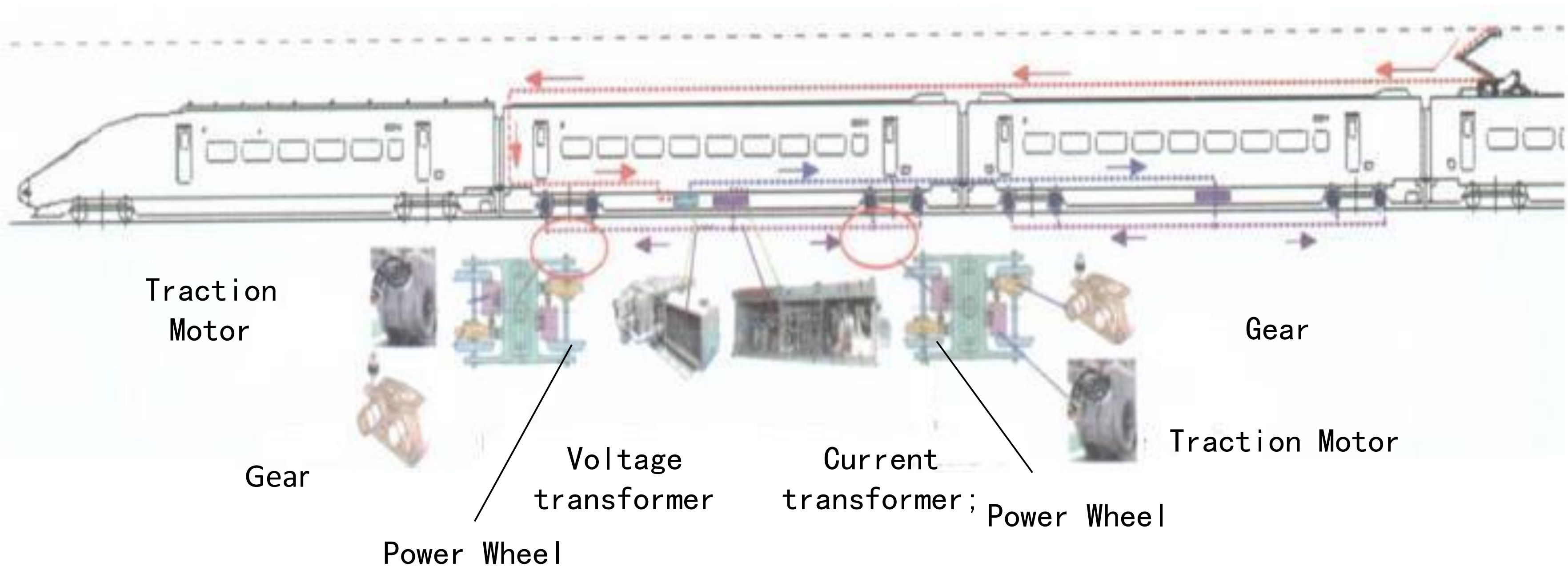
- Its rotation can be much higher
- Its rotation rate is: 7,000 per minute, or 116/s
- Light weight, small size
- It took 70 years to make AC motor widely used
- It requires both voltages and frequency to be adjustable, variable voltage variable frequency (VVVF)
- The development of electronic power equipment makes VVVF practical

VVVF


AC
Transformer
Rectifier
DC-Link
L
Inverter
M
Variable
voltage
Variable
frequency
(c)


AC
(b)
Transformer
Rectifier
DC-Link
C
Inverter
M
Constant
voltage
Variable
voltage
and
frecuency
(d)
(VVVF)

Engine


Traction Motor
Gear
Voltage transformer
Current transformer;
Power Wheel
Power Wheel
Gear
Traction Motor

Key technologies

- High voltage
- 2*25 kv system
- Improved overhead contact line
- Improved pantograph
- Improved engine

Rolling Stock for HSR

Key technologies

- System integration
- Train body
- Truck
- Brake and control

Vehicle design

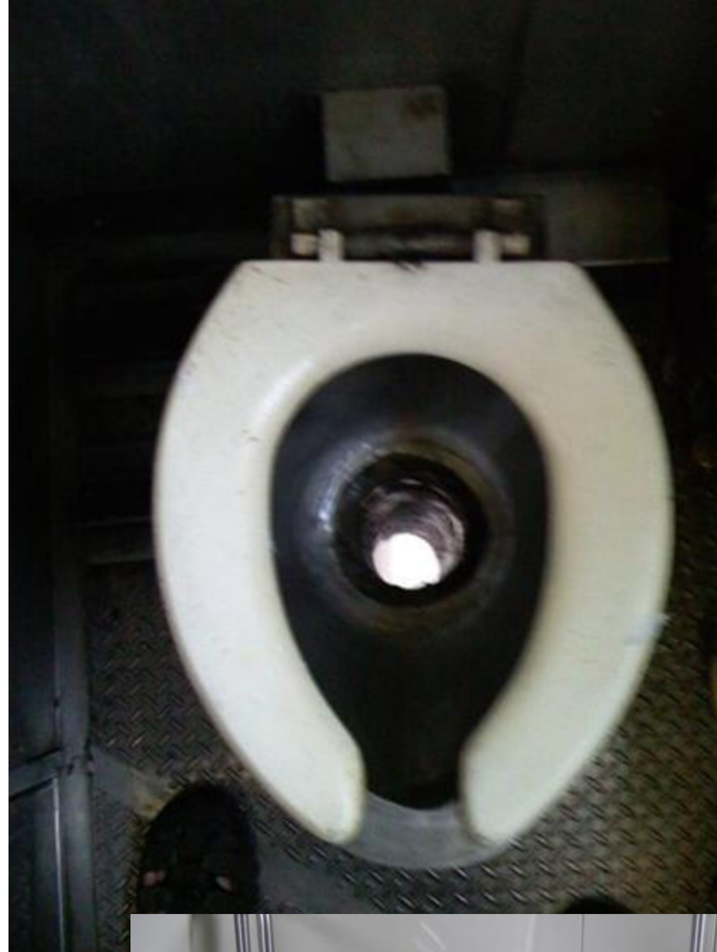
- Train shape
  - Surface air pressure when trains meet
    - Door, window sealing damage, window glass broken, ear uncomfortable
  - Surface air pressure in tunnel
    - Train speed, cross section area vs. tunnel cross section (congestion coefficient), train nose length vs. train body cross section area, friction between side of vehicle body and tunnel
  - train induced air flow
    - Hazard to worker along tracks

Vehicle design (cont.)

- Light weight design
  - Light weight materials
    - Stainless steel, aluminum alloy, atmospheric corrosion resisting steel
  - Vehicle body structural design
  - Vehicle body seal technology
    - Continuous welding, sealing glue
    - Fixed window
    - .
    - .
    - .

Vehicle design (cont.)

- Vehicle body sealing
  - Welding and sealing
  - Fixed widow
  - plug type door, rubber strip seal
  - Air condition air exchange pressure control
  - Toilet on high speed train

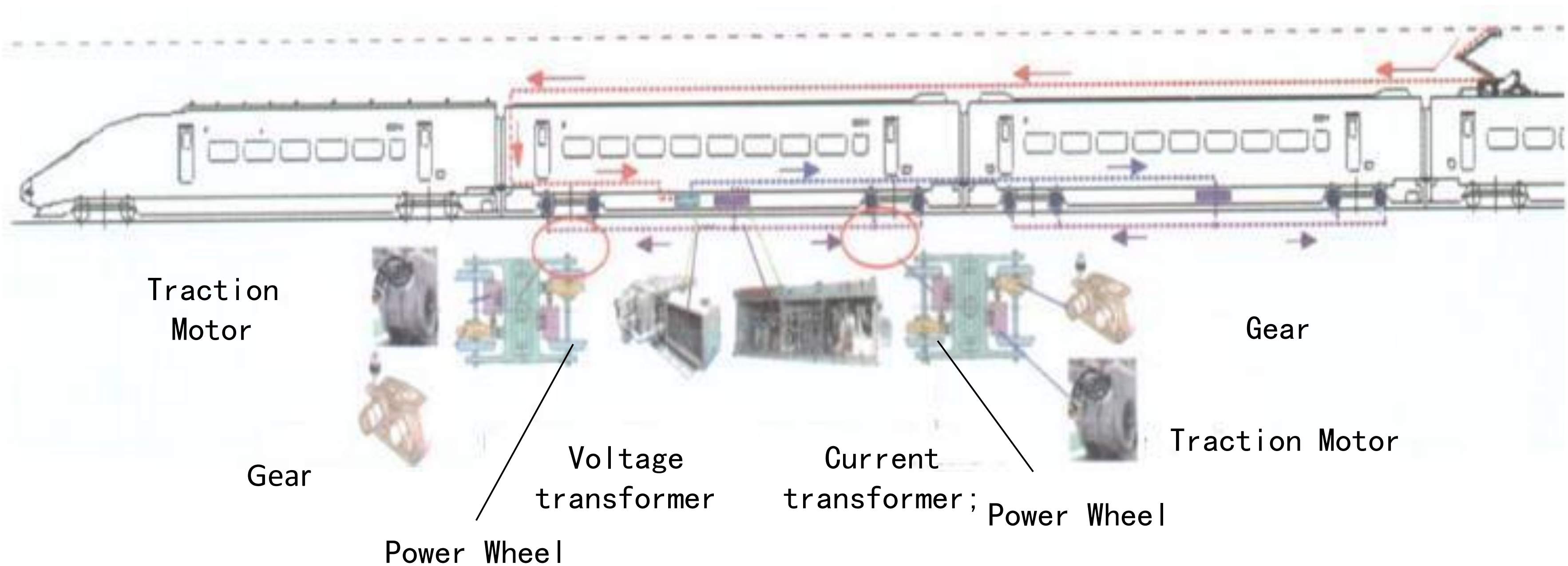


Vehicle design (cont.)

- Noise reduction
  - Noise from vehicle
    - Improve body stiffness, reduce vibration migration, increase thickness
    - Sound proof, anti-vibration, double layer window
    - Streamlined vehicle body
  - Interior design
    - Sound insulation, noise absorption materials
    - Room arrangement
    - Floor noise reduction
  - Equipment installation noise reduction
  - Window noise reduction
  - Developing new materials

Vehicle design (cont.)

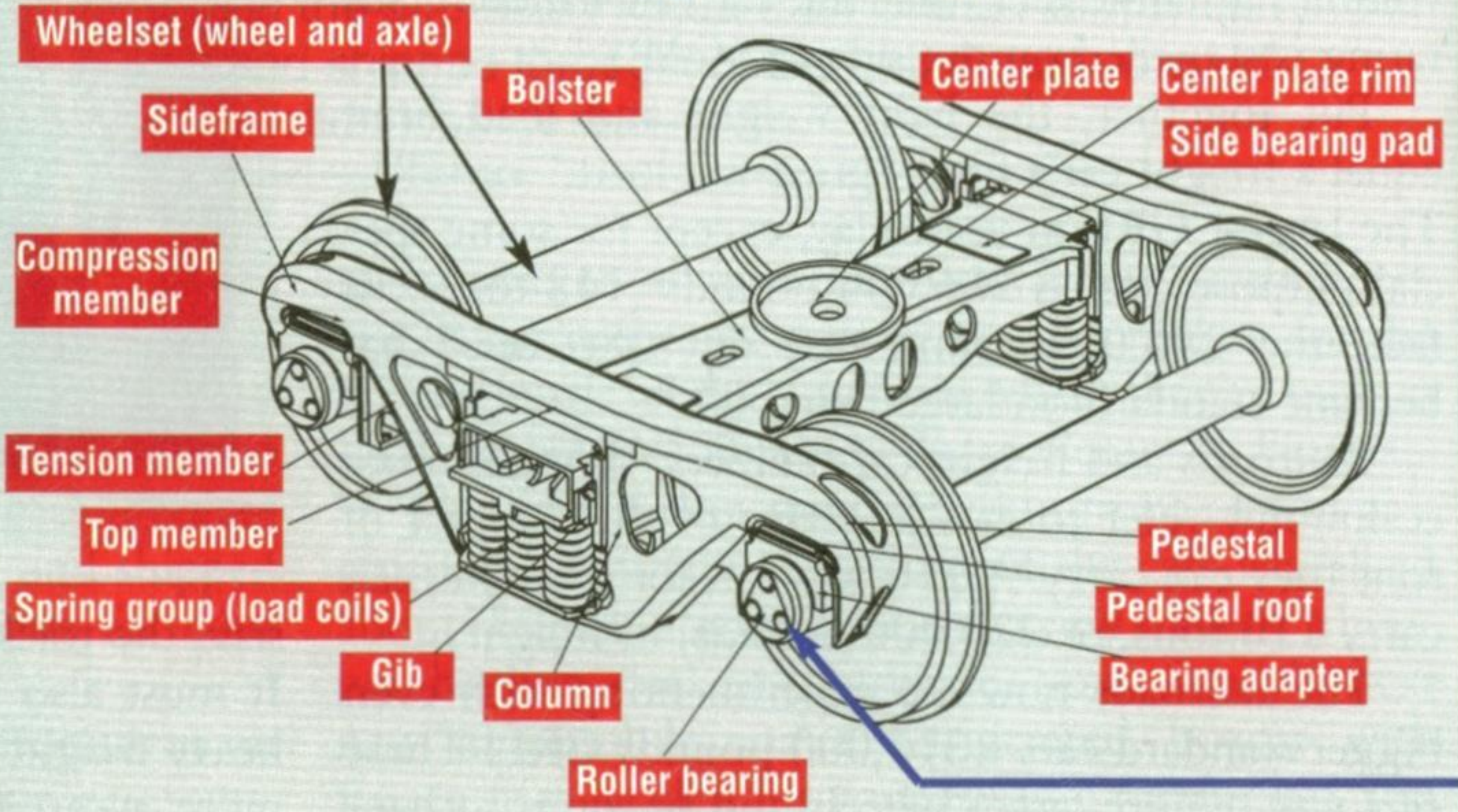
Trucks (bogie)



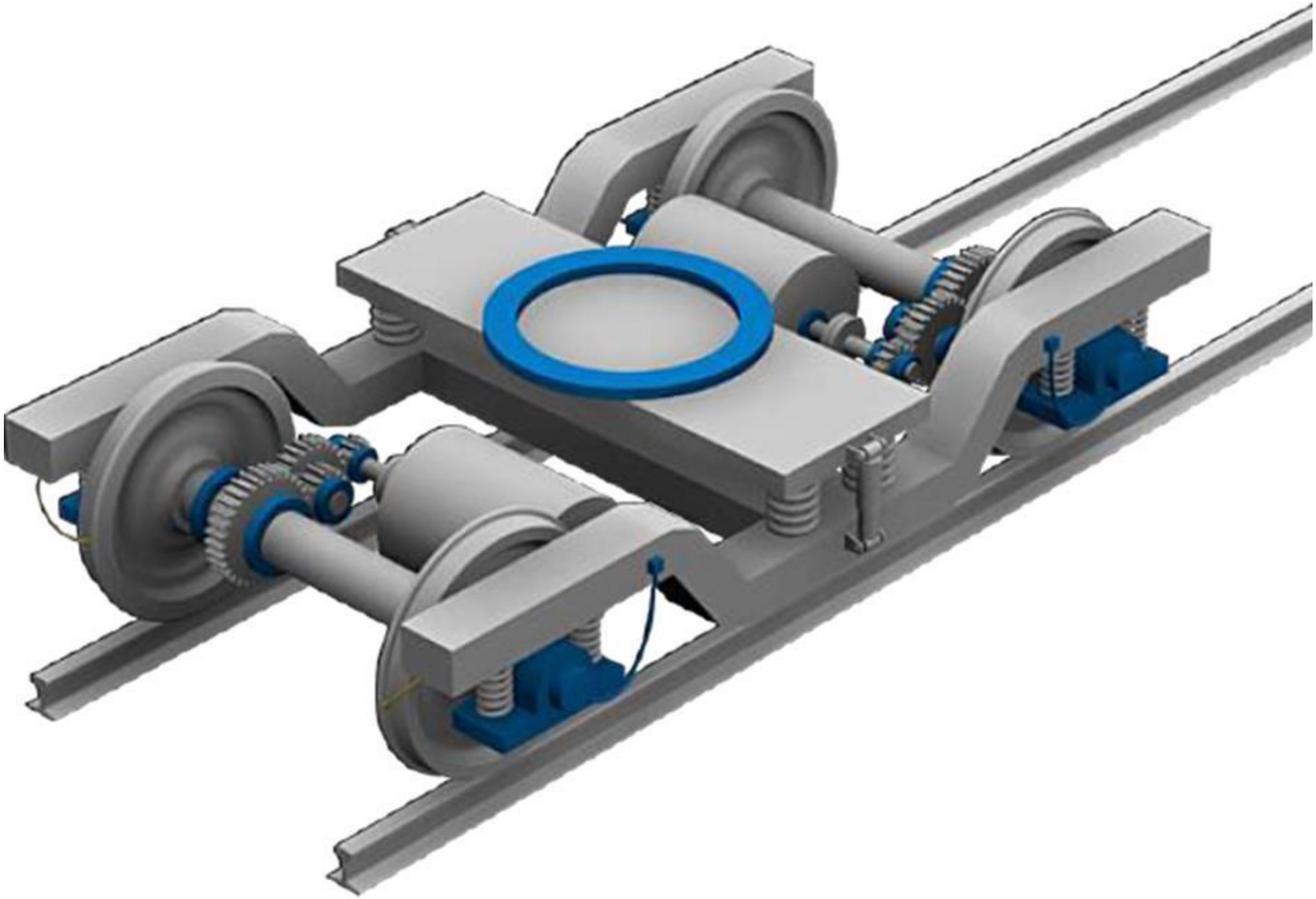
Truck (cont.)

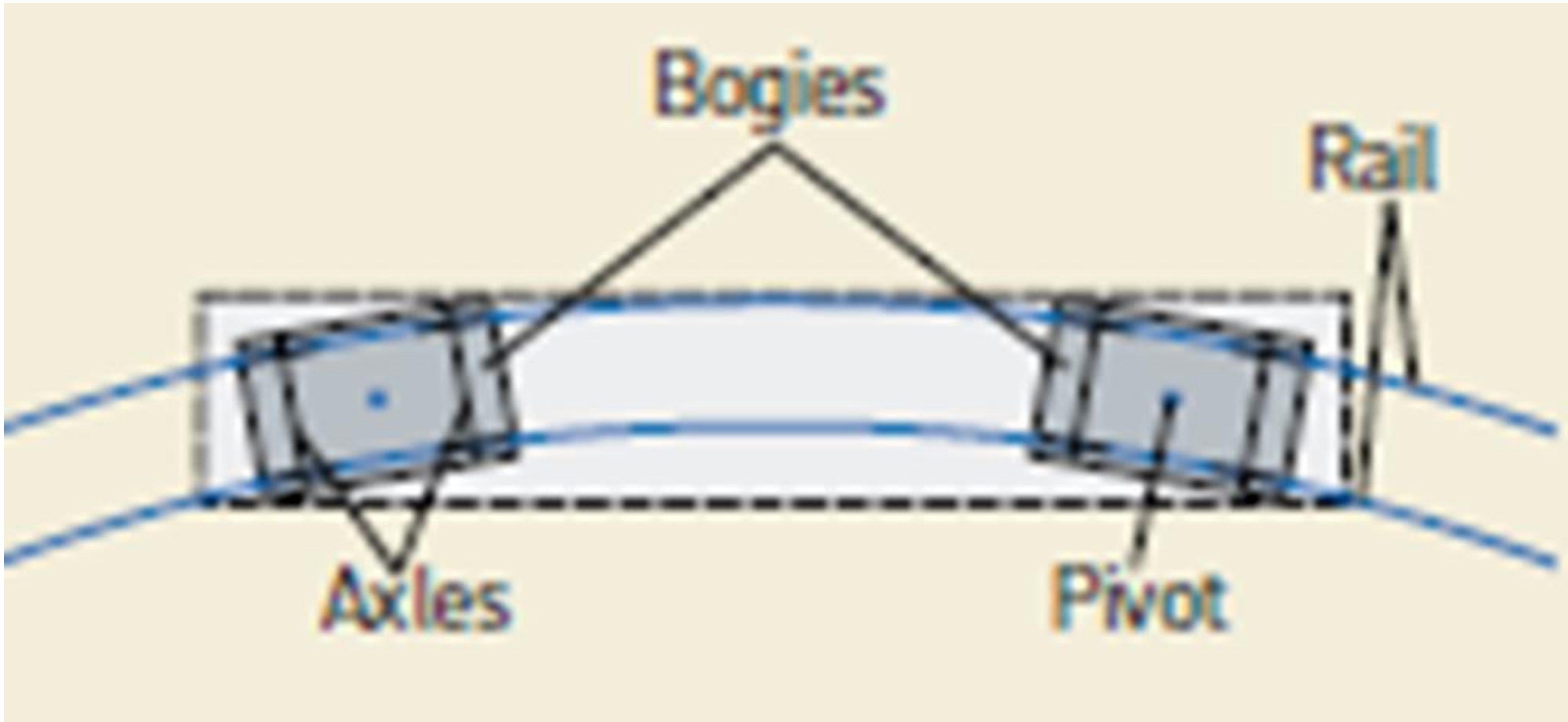
- Concentrated power (France)
  - Easy for maintenance
  - Ventilation for cooling
  - Reduce car load
  - Reduce noise
- Distributed power (Japan)
  - Axial load small
  - Traction power big
  - Acceleration quick
  - Friction coefficient good
  - Higher speed

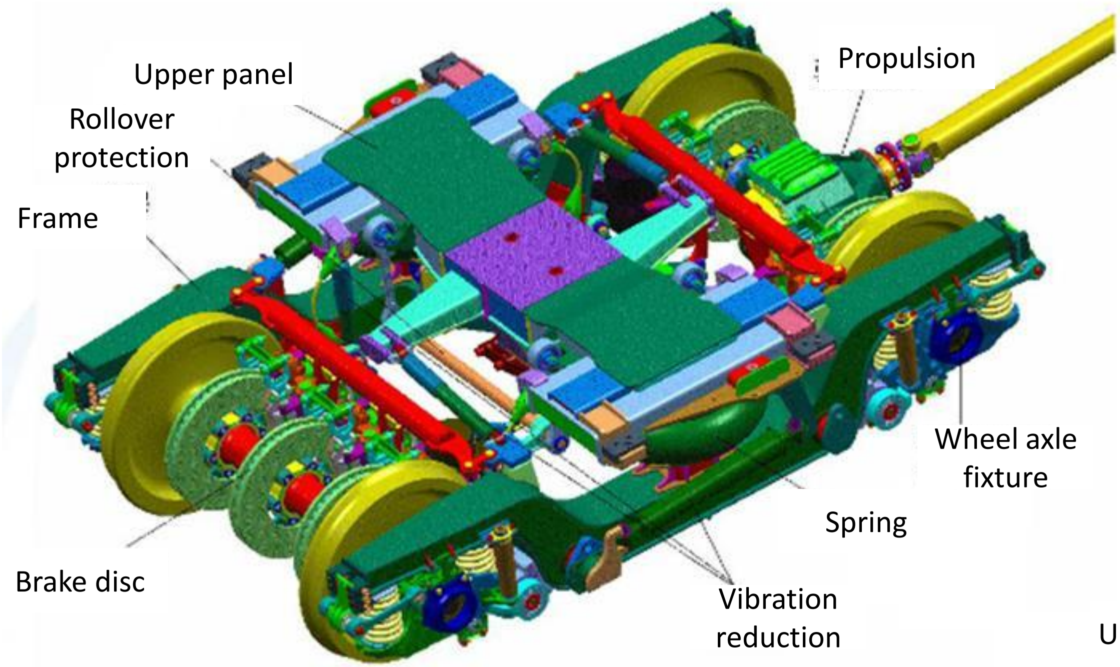
Basic parts of a three-piece freight car truck



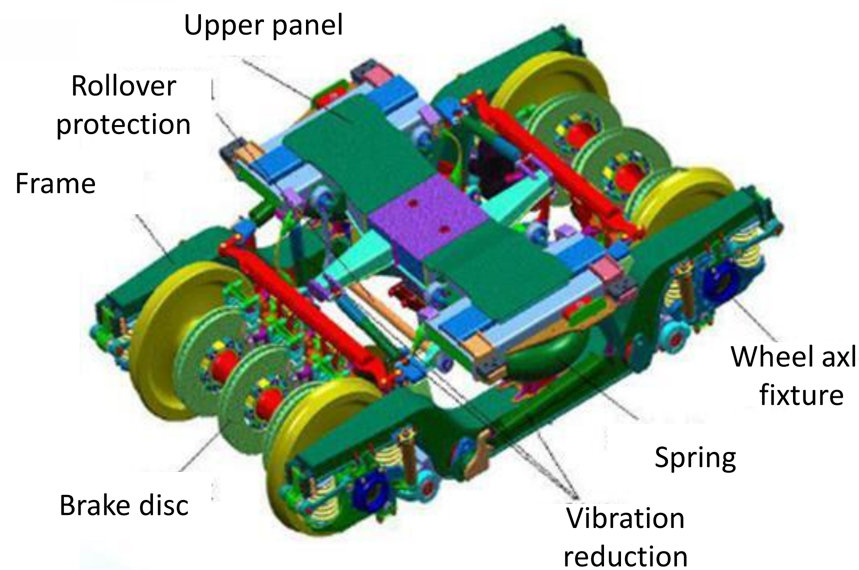
American Steel Foundries illustration




Bogies
Rail
Axles
Pivot



Truck with power



Truck w/o power

Bogie weight reduction

- Welding structure than cast steel structure
- Hole-bored axle, small diameter wheel
- Journal box, gear box

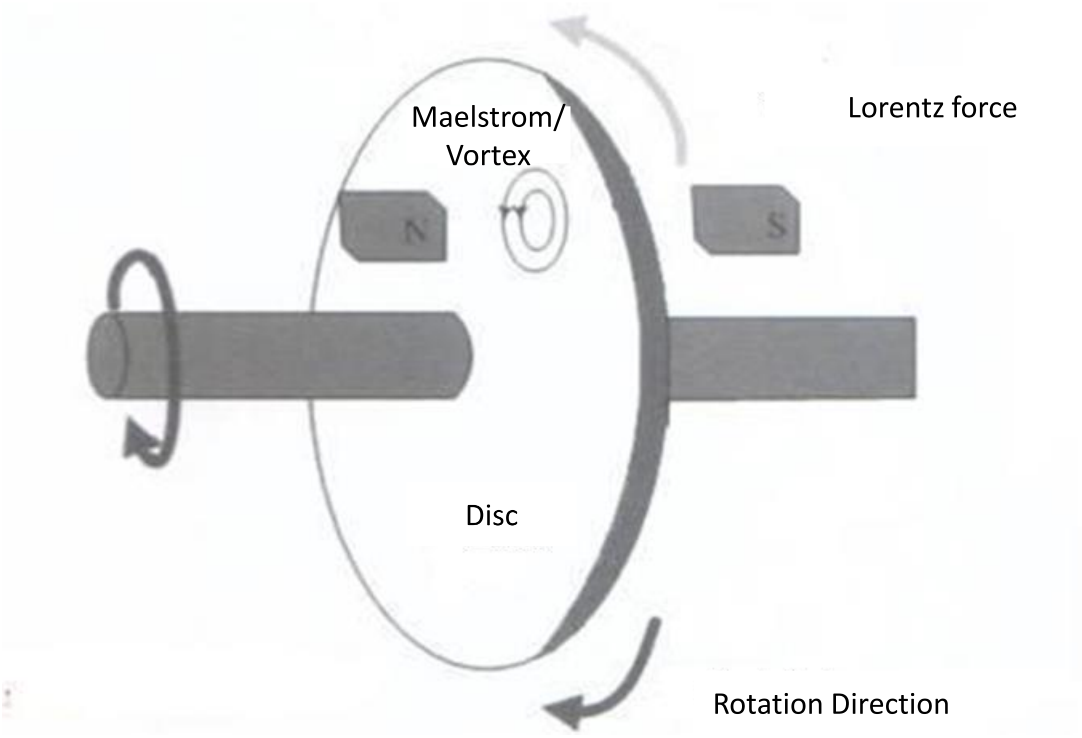
Braking and its control

- Braking system requirements
  - Braking distance
    - Normal
    - Emergency braking: 3000-4000 m
  - Comfort
    - Jerk <0.6 m/s2, no obvious uncomfortable
    - 0.6-0.75 m/s2, acceptable
    - >1.0 ms2, fail
  - Reliability
    - System component reliable
    - Fail safe

Braking technologies

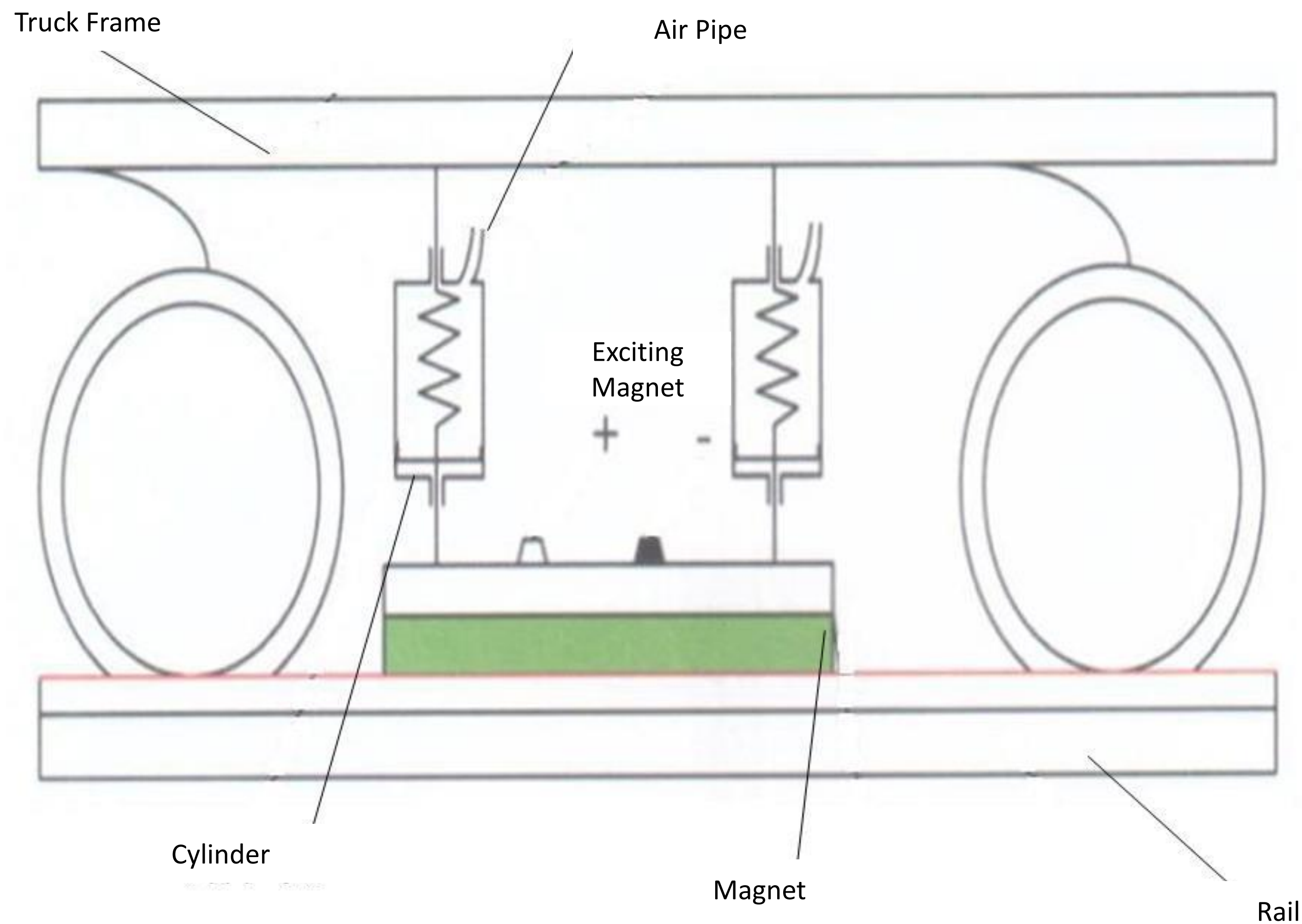
- Disc brake
- Rheostatic brake, dynamic brake
- Regenerative brake
- Magnetic rail brake
- Electromagnetic rail brake (Eddy current brake)
- Rotary electromagnetic brake
- Wind resistance brake

Lorentz force

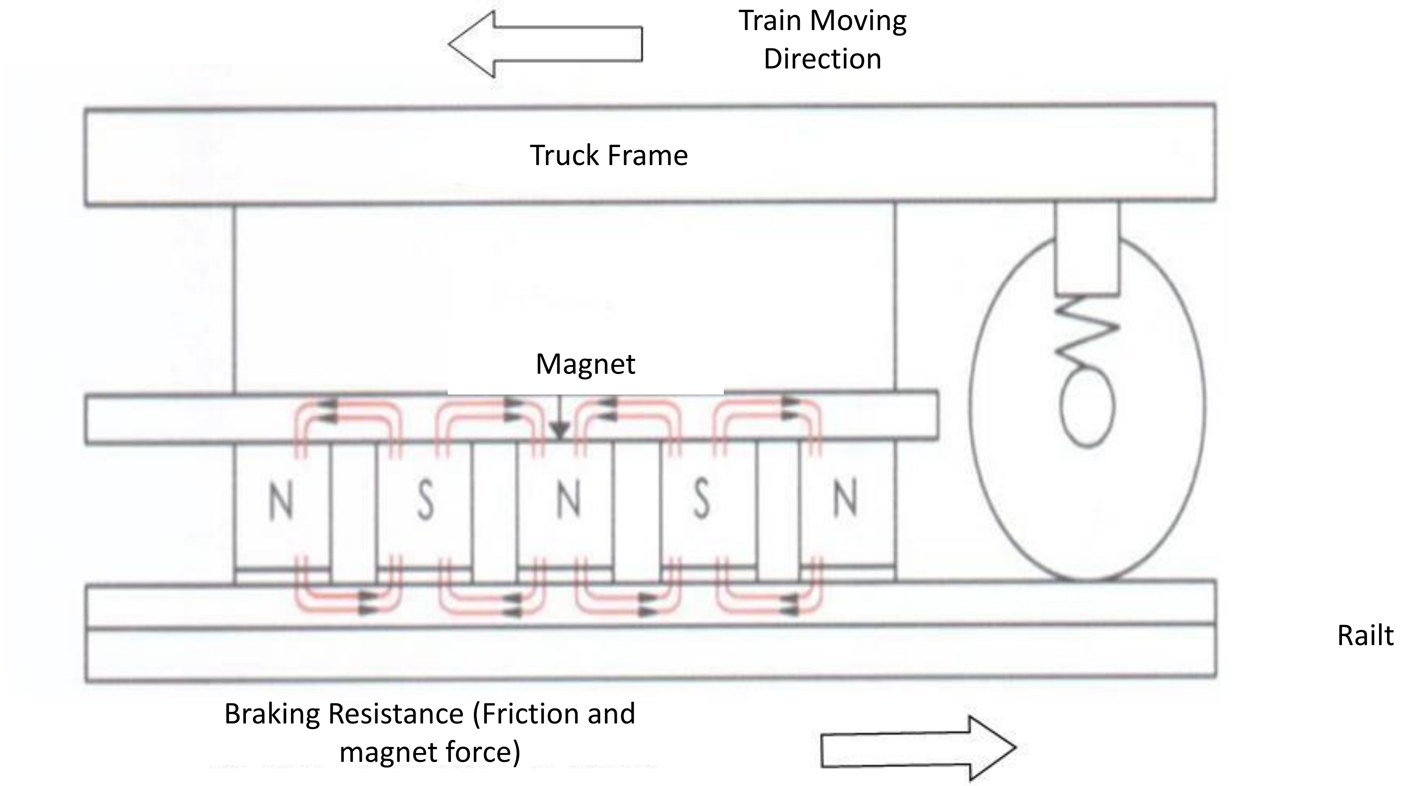


- dynamic brake

- http://en.wikipedia.org/wiki/Eddy_current_brake



- electromagnetic rail brake



- electromagnetic rail brake

Braking technologies - type

- Friction braking
  - Disc brake
  - Magnetic rail brake
- Traction braking
  - Rheostatic brake, dynamic brake
  - Regenerative brake
  - Electromagnetic rail brake (Eddy current brake)
  - Rotary electromagnetic brake
- Wind resistance brake

Braking technologies - type

- Friction braking
  - Braking force does not change with speed
  - Braking force is limited
  - Limited by heat dissemination
- Traction braking
  - Change with speed

Braking technologies - type

- Adhesion braking
  - Disc brake
  - Rheostatic brake, dynamic brake
  - Regenerative brake
  - electromagnetic rail brake (Eddy current brake)
  - Rotary electromagnetic brake
- Non-adhesion braking
  - Magnetic rail brake

Integrated braking systems

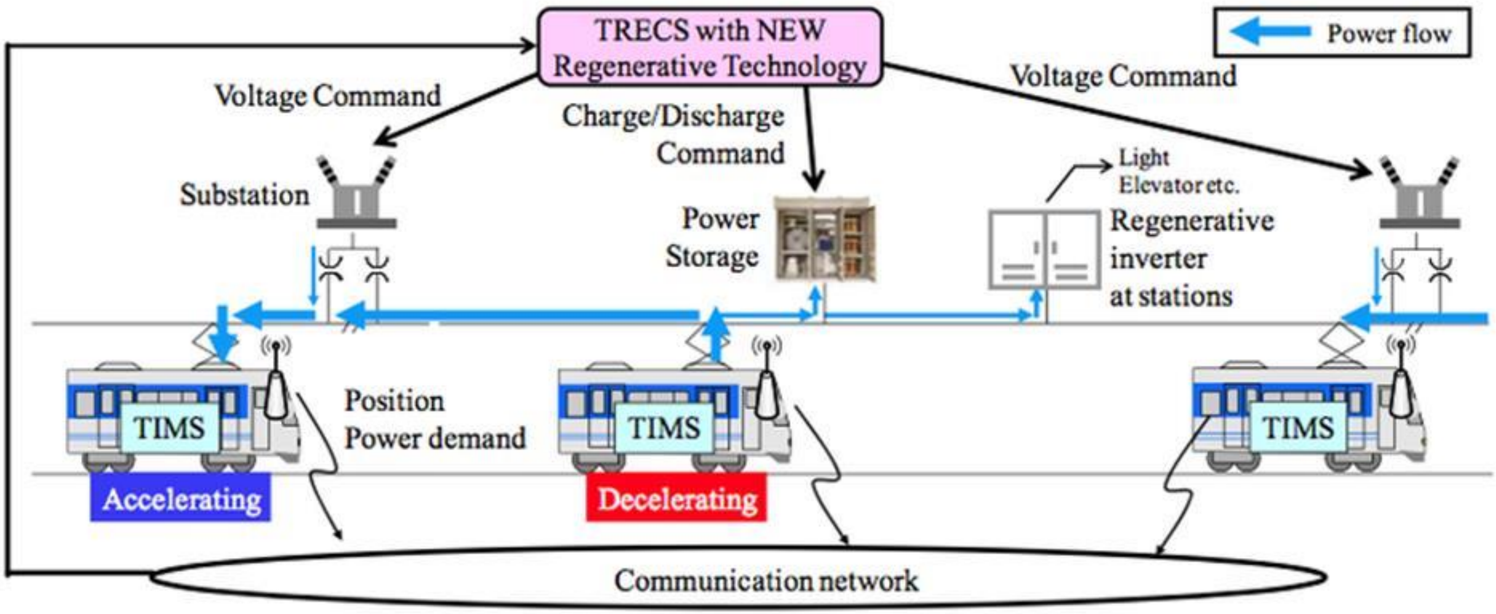
- Japan, 270 mph, regen + disc
- ICE1, 300 mph, regen + disc + ElectMag Rail
- TGV-A, 300 mph,
    - veh w/ motor: regen + surface
    - Veh w/o motor: regen + surface, disc

列车型号	运营时速（公里）	制动方式	拖车制动盘数/轴	标准制动距离（米）	不良状态制动距离（米）
300系（日本）	270	再生+盘形	2	4000	4960
ICE1（德国）	300	再生+盘形+磁轨	4	3450	——
TGV-A（法国）	300	动车：电阻+踏面 拖车:盘形	4	3500	4500
TGV-PSE（法国）	270	动车：电阻+踏面 拖车：盘形	4	3000	3700

Braking control system

- Air braking control system – supplementary system for HSR
- Electronic braking control system

High speed rail traction network control system



TRECS: TRaction Energy Control System, TIMS: Train Integrated Management System

High speed rail traction network control system

- Control
  - Coordination between vehicle with power
  - Traction control
  - Speed setting
  - Auxiliary system control
  - Phase control
  - Train operation and monitoring
  - Air and electrical braking
- Failure diagnostics and treatments

- Information display and setting
- Data storage

In-vehicle air environment control system

- Air environment control
  - Ventilation, cooling, heating, humidifier, automatic control
- Air pressure control

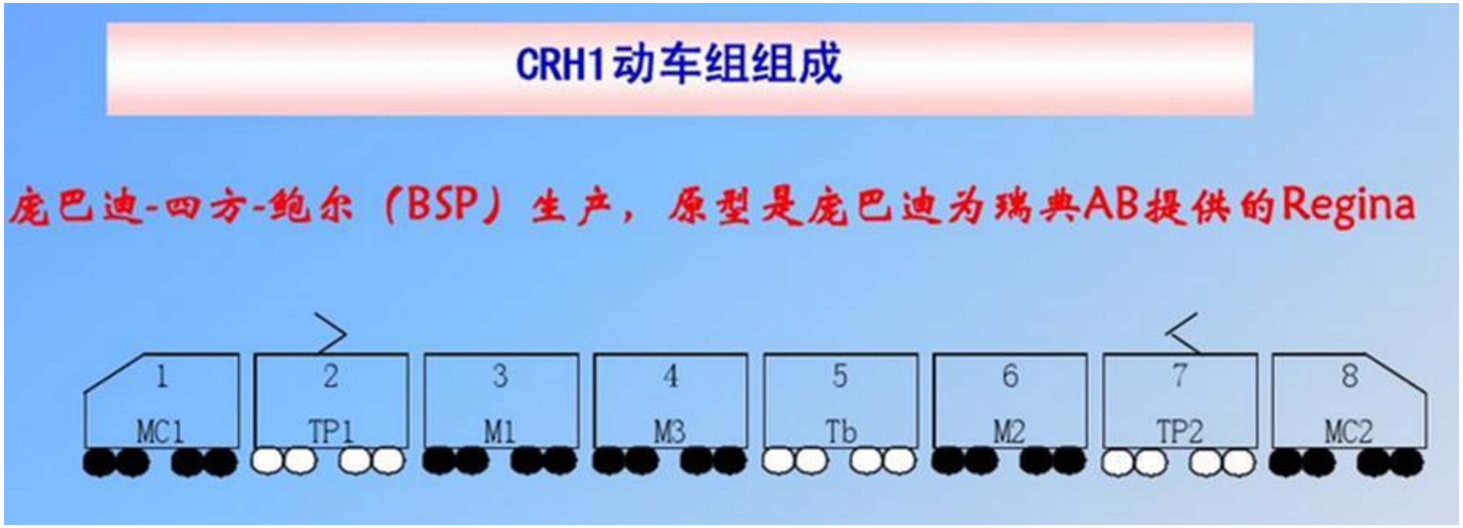
Tilting train

- http://www.alstom.com/products-services/product-catalogue/rail-systems/trains/products/pendolino/

Tilting train (cont.)

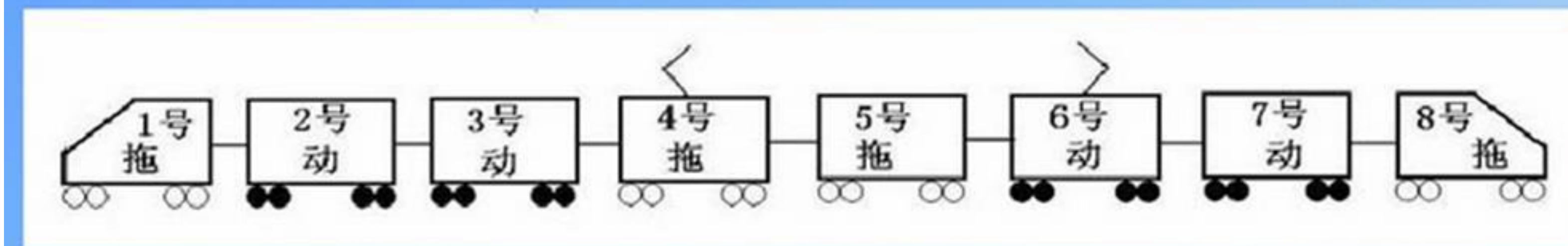
- Trains with tilting by inertial forces (a few countries)
- Trains with active tilting with sensory information given by accelerometers (Bombardier)
- Trains with tilting controlled by a computer (many countries)
- Trains with active suspension (Japan)

CHR


CRH1动车组组成
庞巴迪-四方-鲍尔（BSP）生产，原型是庞巴迪为瑞典AB提供的Regina
1 MC1
2 TP1
3 M1
4 M3
5 Tb
6 M2
7 TP2
8 MC2

- 200 kmh

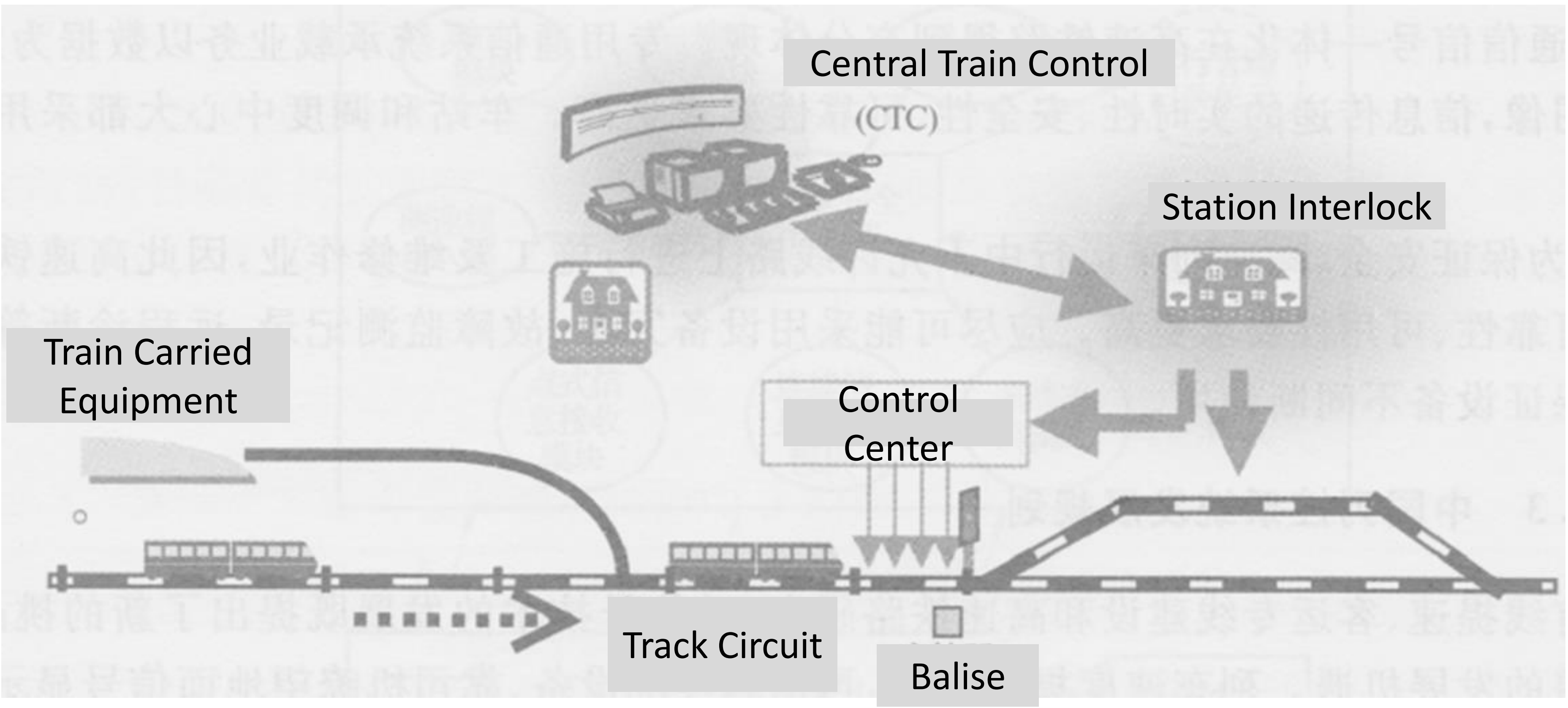
CRH2动车组组成及主要参数

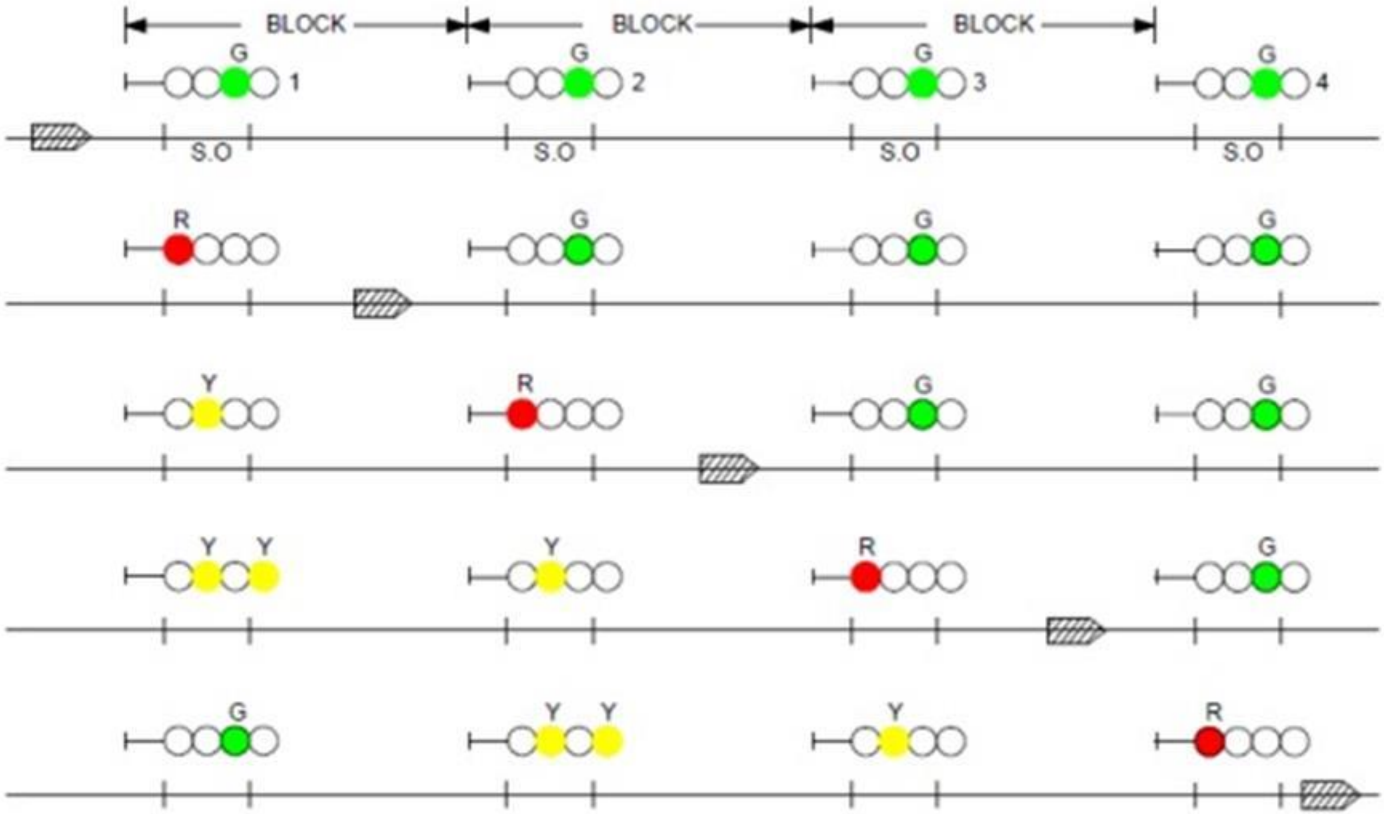


HSR signal and control

HSR signal

- **Train operation control**
  - Train operation permit
  - Speed target
  - Monitoring and control
- **Station interlock**
  - In real-time setup routing of switching for entering, leaving and within station
- **Dispatching**
  - Develop operation plan and implement it
- Diagnostics and service
- Monitoring system
- Hazard information treatment
- Communication network

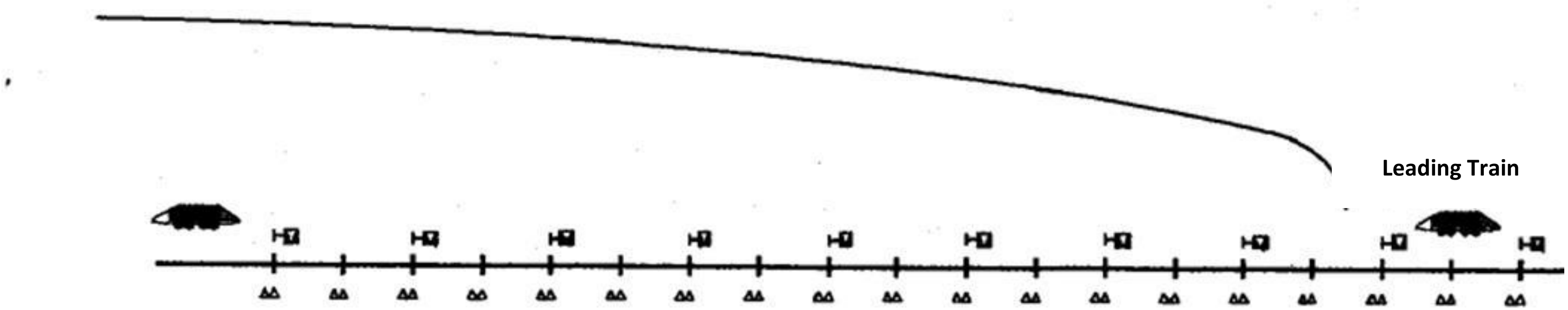

Central Train Control
(CTC)
Station Interlock
Train Carried Equipment
Control Center
Track Circuit
Balise



FOR SIGNAL.1. TO ASSUME YELLOW - LINE MUST BE CLEAR FOR ONE BLOCK AND ONE OVERLAP
FOR SIGNAL.1. TO ASSUME DOUBLE YELLOW - LINE MUST BE CLEAR FOR TWO BLOCKS AND ONE OVERLAP
FOR SIGNAL.1. TO ASSUME GREEN - LINE MUST BE CLEAR FOR THREE BLOCKS AND ONE OVERLAP

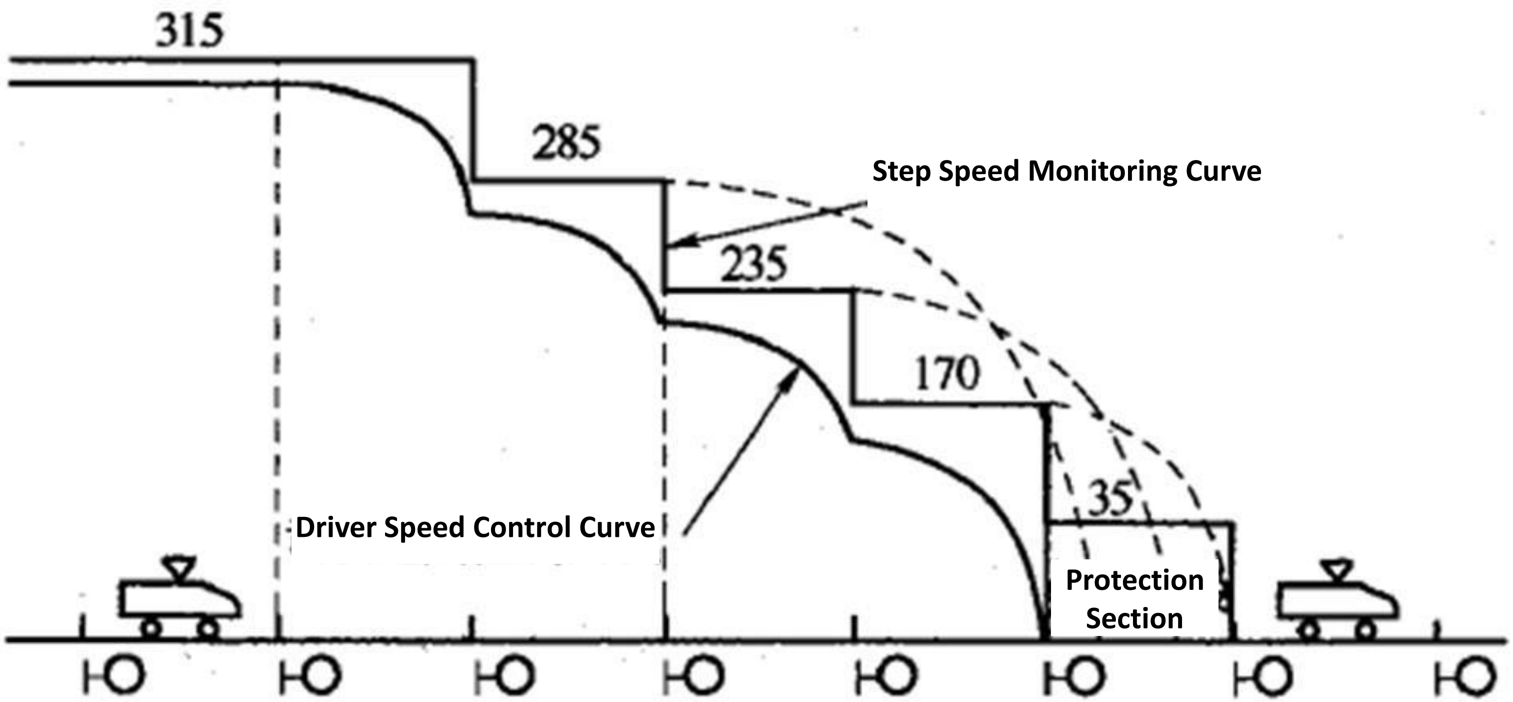
- http://www.cr.indianrailways.gov.in/view_section.jsp?lang=0&id=0,6,287,394,576

Train interval control and **speed control**

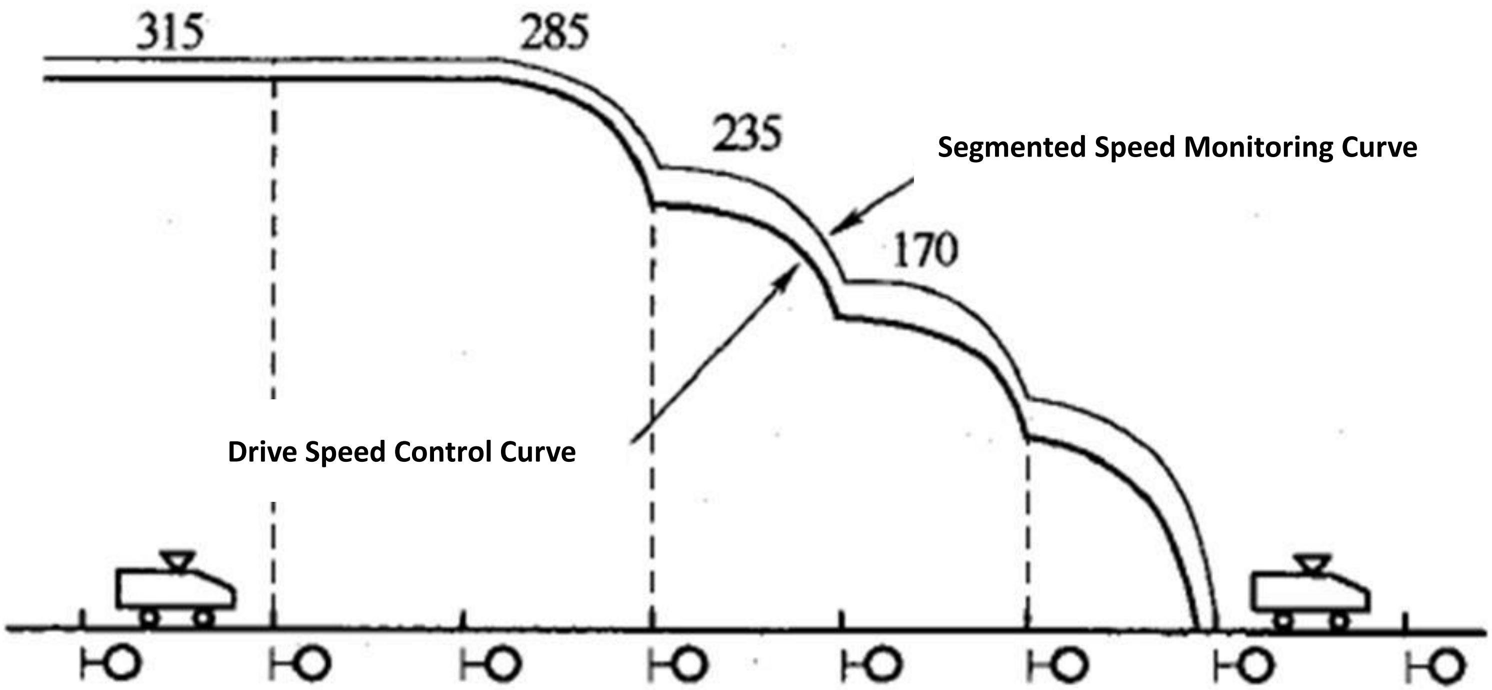


Track circuit	TC0	TC1	TC2	TC3	TC4	TC5	TC6	TC7	TC8	TC9	TC10	TC11	TC12	TC13	TC14	TC15	TC16	TC17	TC18	TC19
Low frequency info	L6		L5		L4		L3		L2		L		LU		U		HU			
Block	B0		B1		B2		B3		B4		B5		B6		B7		B8			

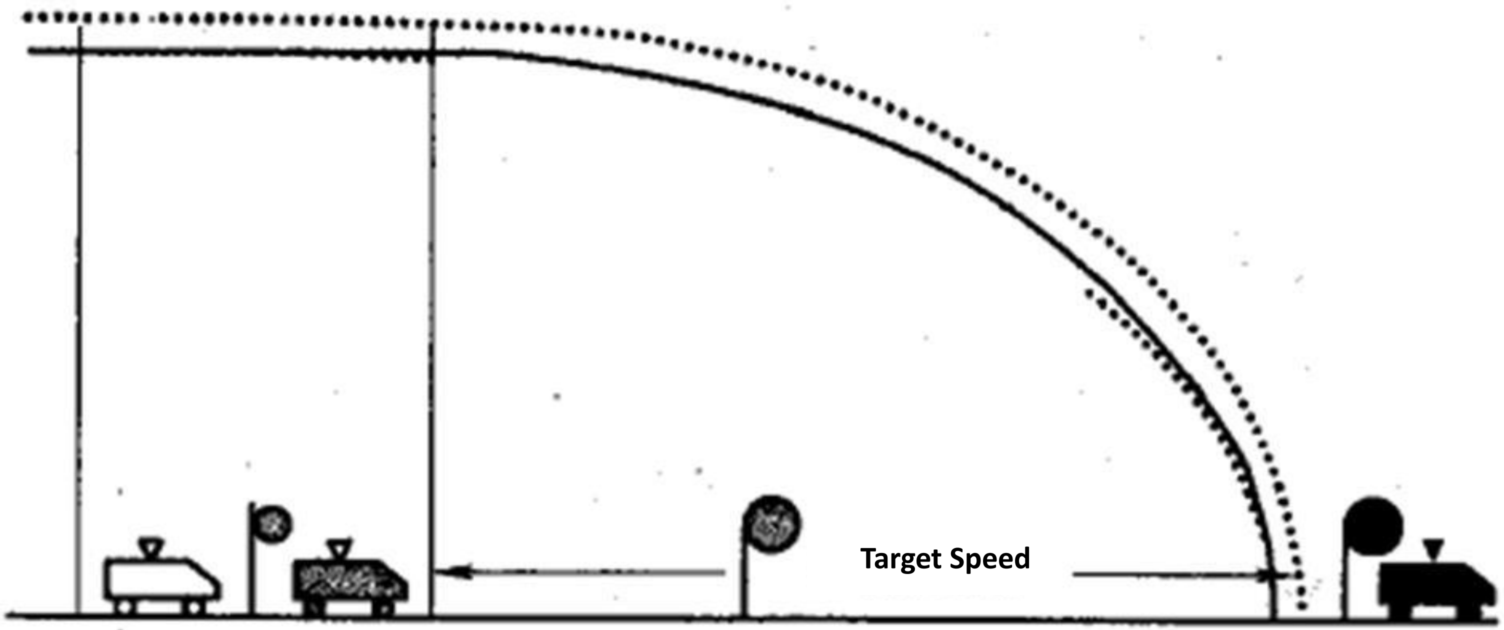
- Average block distance: 2,000-2,400 m
- Interval: 3 min
- Train distance gap: 13,500 m



315
285
Step Speed Monitoring Curve
235
170
35
Driver Speed Control Curve
Protection Section



315
285
235
Segmented Speed Monitoring Curve
170
Drive Speed Control Curve


Target Speed

Train interval at station

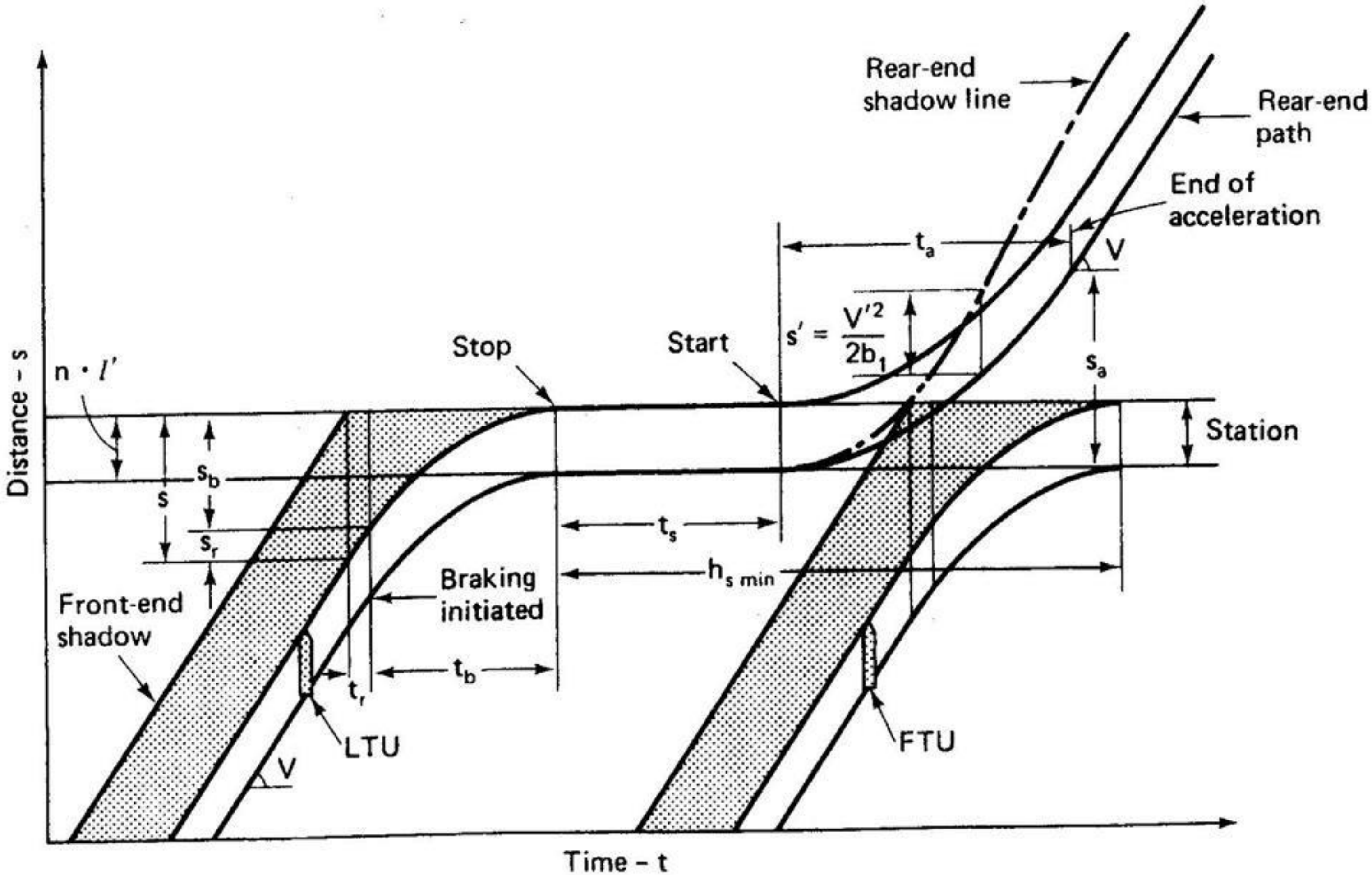


Figure 4.12 *Time-distance elements of departure/arrival and headway between consecutive TUs at a station for $b_1 < \infty$*

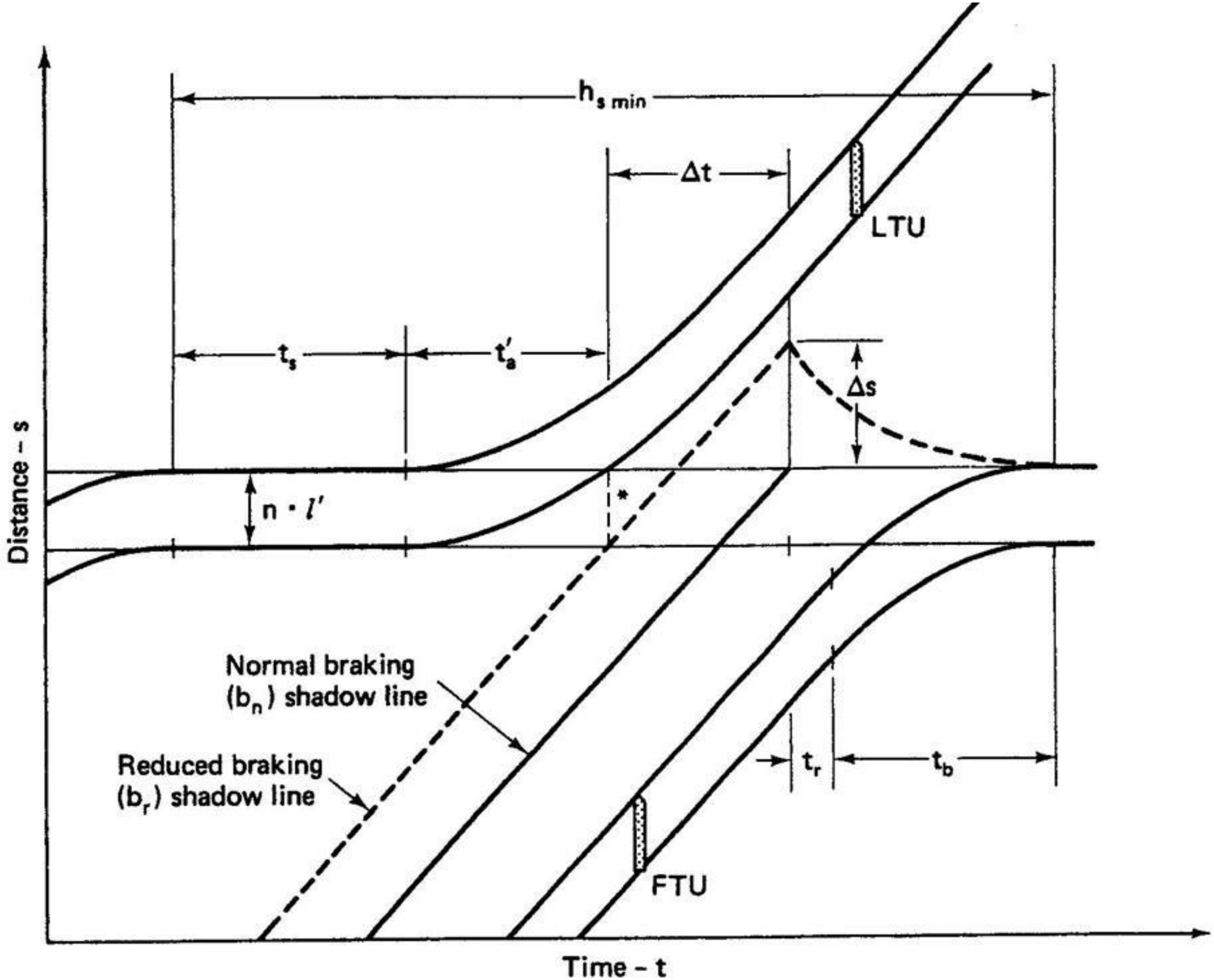


Figure 4.13 Minimum station headway with safety requirements typical for rapid transit systems

- Train interval between stations

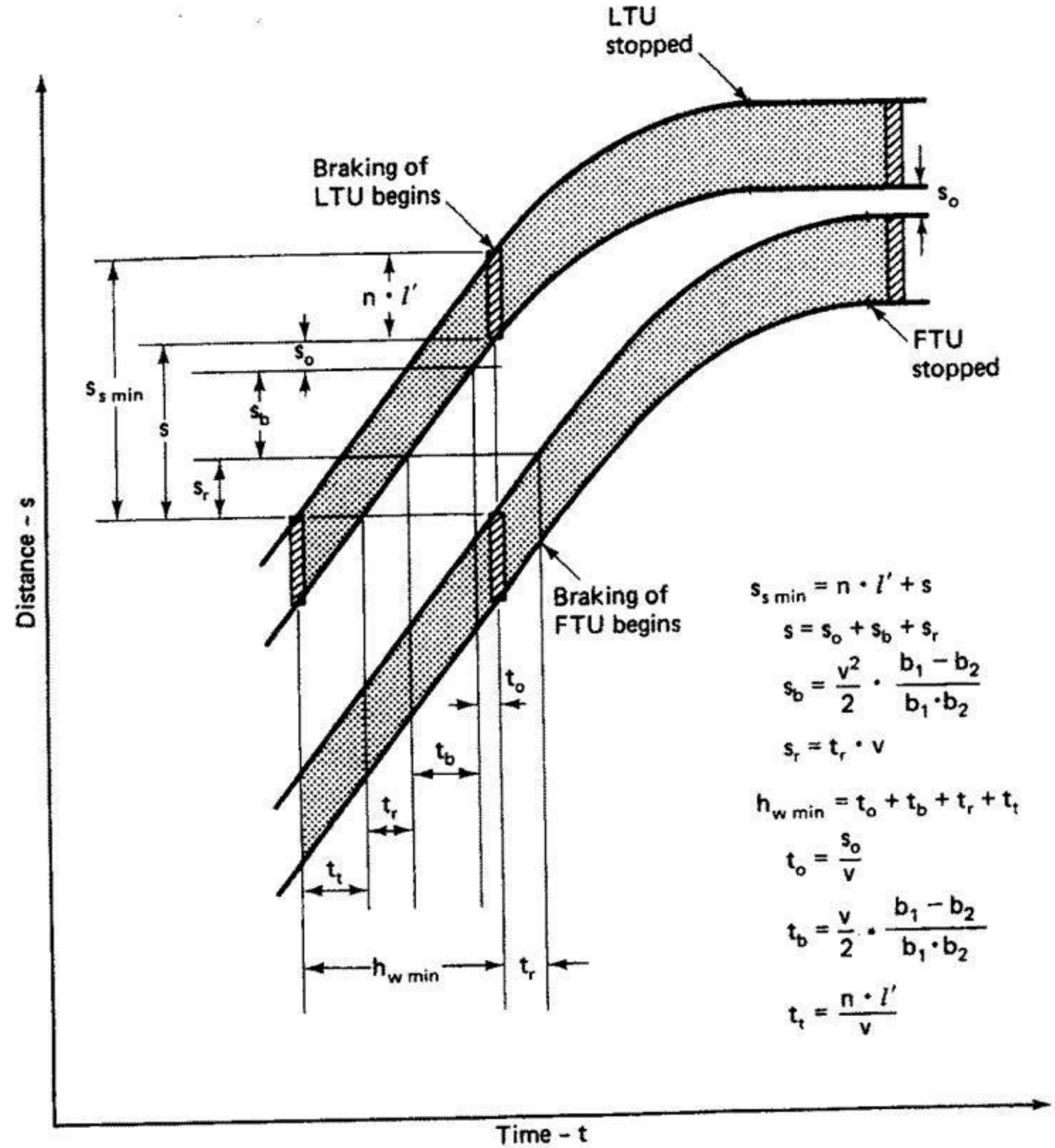


Figure 4.4 *Components of TU headway, spacing, and stopping distance*

Key technologies

- Standardization: interaction between signal, communication, trackside
- Trackside-train data transmission
  - Continuous, point based; one direction, bi-direction,
    - Rail inductive loop, wireless mobile communication (GSM-R), Balise
- Train position system
  - GPS, Balise, rail inductive loop
- Speed measuring system
  - Radar
- Train integrity and occupancy
  - Train end GPS, rail inductive loop
- Interoperable

Balise

System components

- Trackside equipment
- Vehicle carried equipment
- Ground-vehicle communication

HSR train operation features

- Automatic train control
- Central train control, no station dispatching involved
- Train-ground information exchange equipment, verifying train location
- Computer controlled interlock
- Hot-box detection, clearance check
- Communication and signal integrated: primary digital
- No work zones

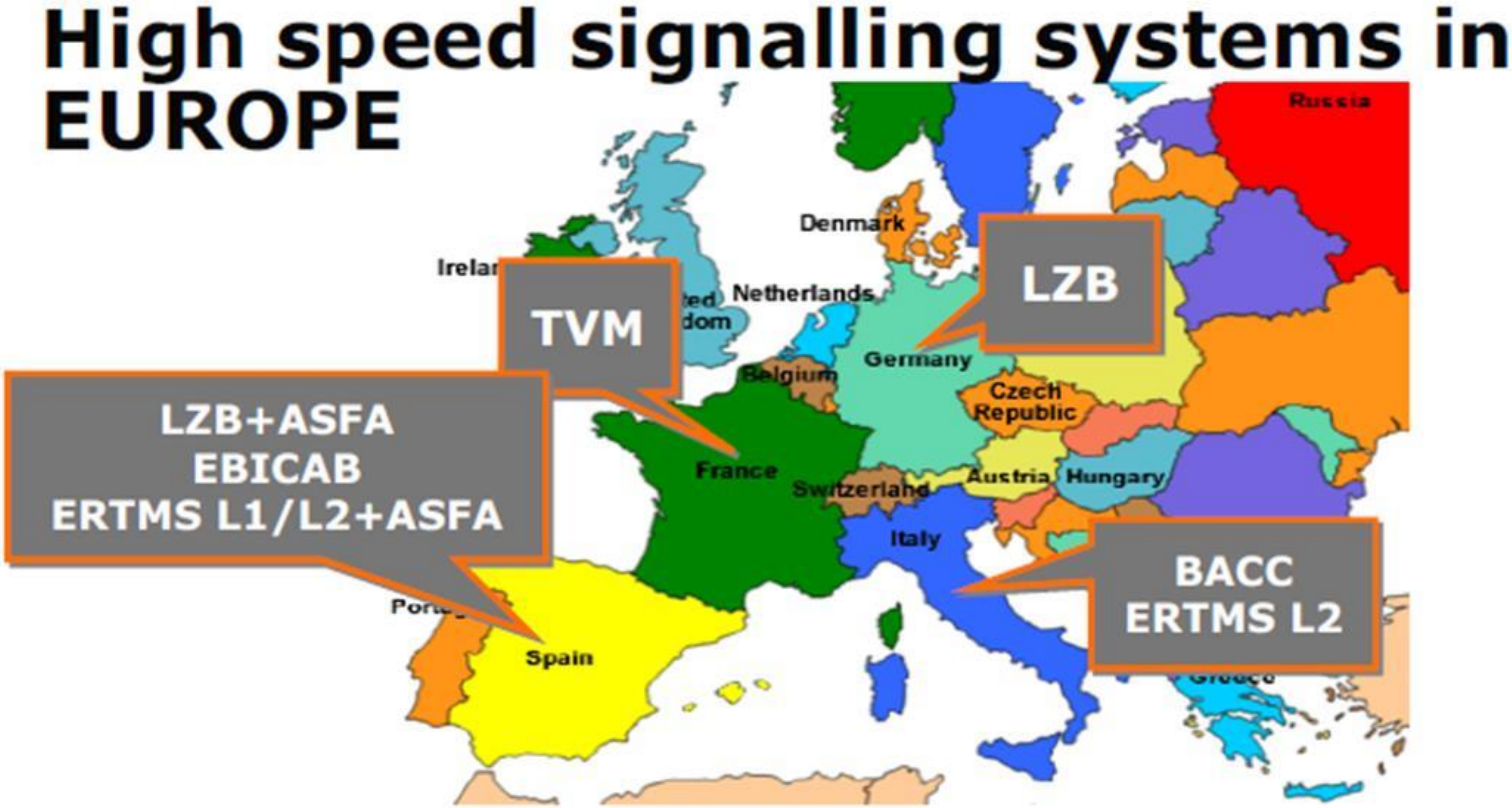
Train control type

- Automatic train protection (ATP) and automatic train control (ATC)
  - ATC is more advanced than ATP
  - ATC is widely used in Japan
- Equipment initiating (better) or driver initiating
  - Equipment initiating: Japan
  - Driver initiating: Germany and France
- Step or continuous speed control
- Point based (mature) and continuous train control (widely used)

ATP

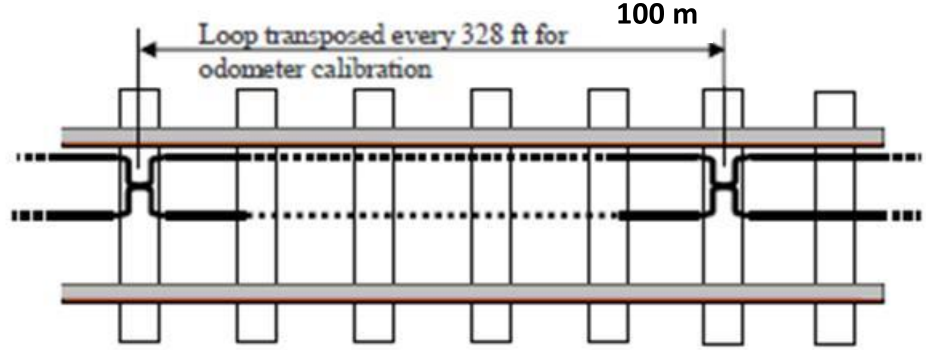
- http://www.youtube.com/watch?v=Q4aWIjbVpcg

Typical HSR train control systems in Europe



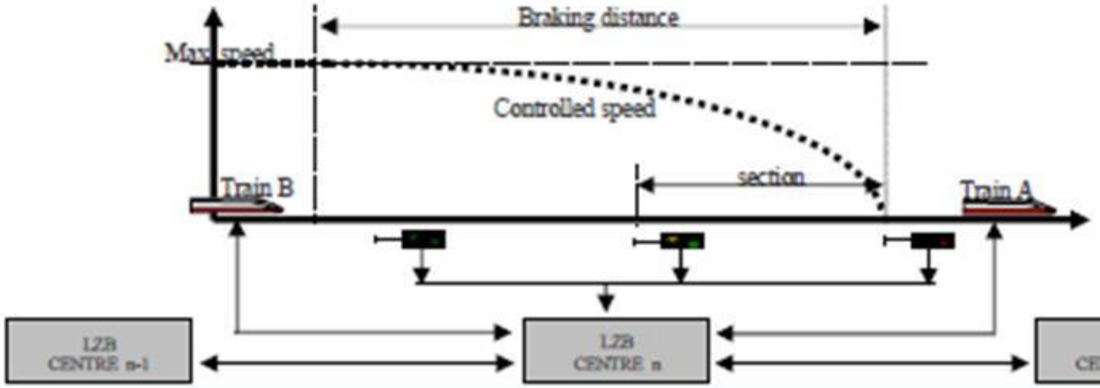
The German signalling system for HS lines LZB (LinienZugBeeinflussung)

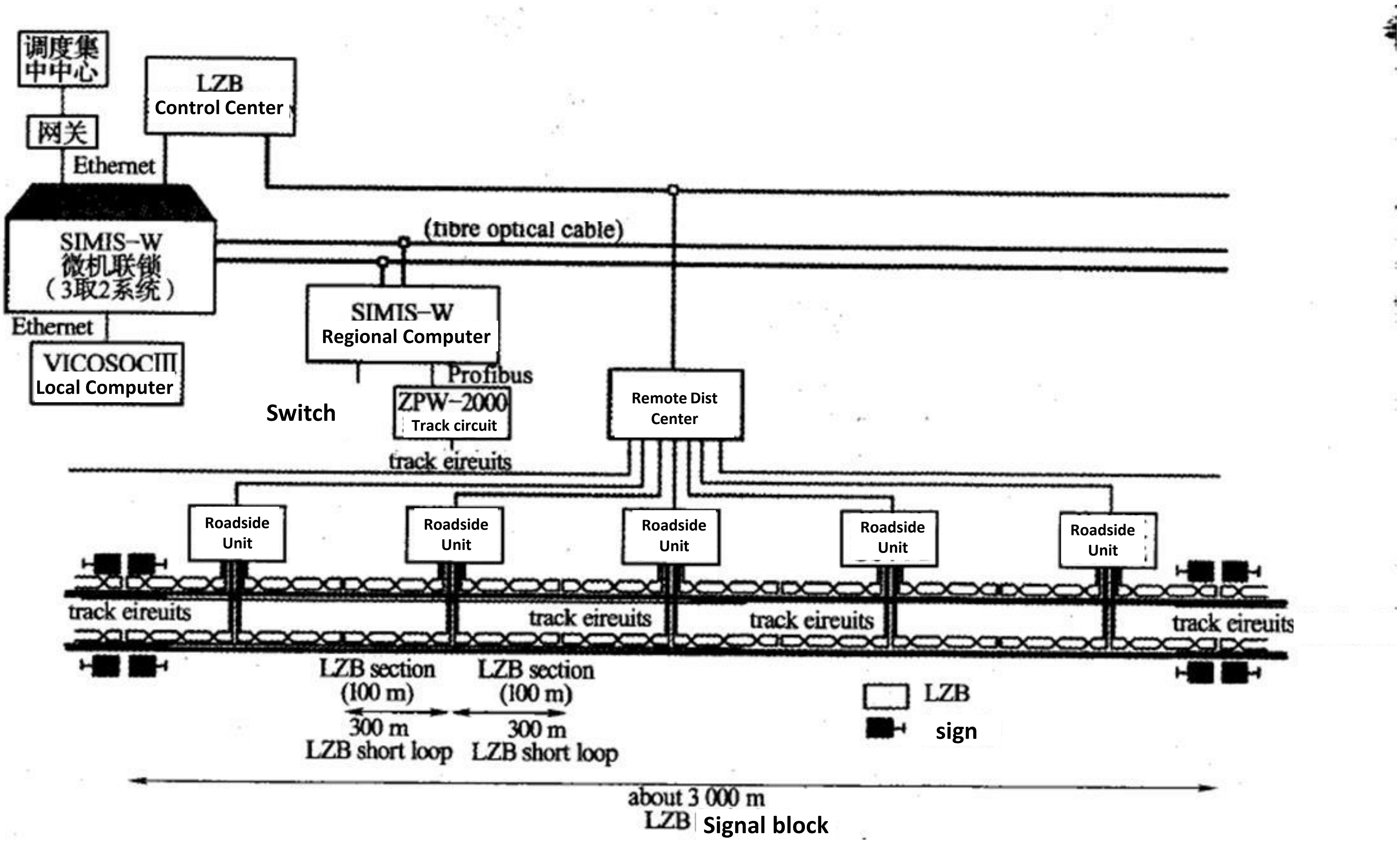
- Vital, computerized, continuous and centralized ATC (Automatic Train Control) system for speed up to 187.5 mph; **62/187=20 min**
- A single centre manages about 62 miles of double track section line;
- The system is overlapped to the national light signalling system;
- The safe bidirectional link train/centre realized with a cable loop laid into the track for all the line length;



The German signalling system for HS lines LZB (LinienZugBeeinflussung)

- Each centre permanently connected to all interlockings and trains of its area as well as to adjacent centers for in and out relationships;
- The trackside vital computer sends cyclically, to every on board computer, data concerning the length of the available braking distance and the localization of braking initiation in respect of the braking train capacity.





调度集
中中心
网关
Ethernet
LZB
Control Center
(fibre optical cable)
SIMIS-W
微机联锁
（3取2系统）
Ethernet
VICOSOCIII
Local Computer
SIMIS-W
Regional Computer
Profibus
ZPW-2000
Track circuit
Switch
track eircuits
Remote Dist
Center
Roadside
Unit
Roadside
Unit
Roadside
Unit
Roadside
Unit
Roadside
Unit
track eircuits
track eircuits
track eircuits
track eircuits
LZB section
(100 m)
LZB section
(100 m)
300 m
LZB short loop
300 m
LZB short loop
LZB
sign
about 3 000 m
LZB Signal block

The Spanish signalling systems for HS lines

- **Speed up to 187.5 mph**

  German LZB overlapped to the national light signalling system ASFA (Anuncio de Señales y Frenado Automatico). The latter is a system for on board repetition of trackside light signals used by conventional trains running the HS lines;

  OR

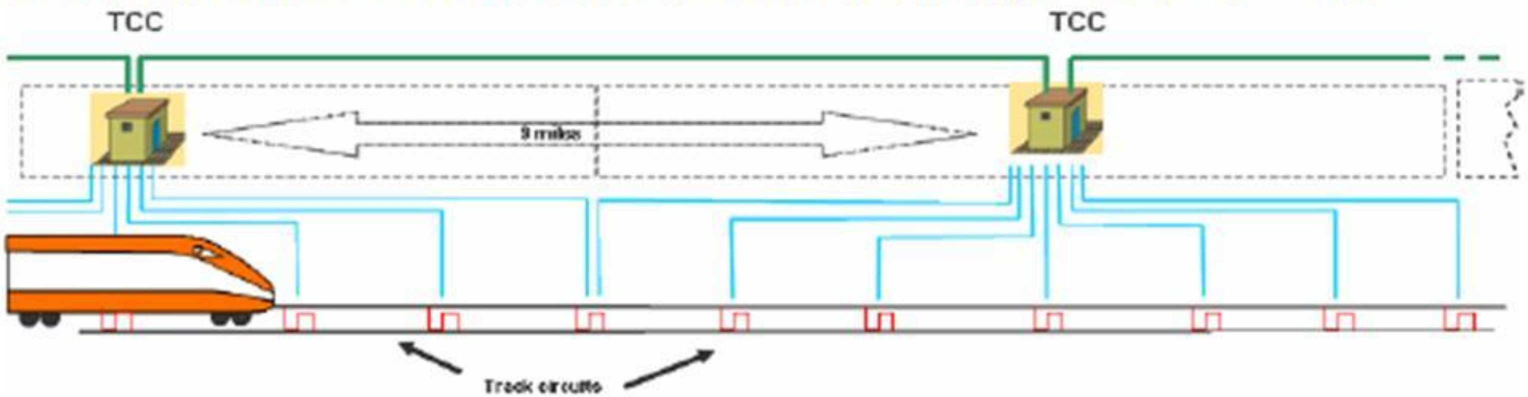
  ERTMS (European Rail Traffic Management System) level 1 and 2, overlapped to the national light signalling system ASFA.

- **Speed up to 137.5 mph**

  EBICAB (Électrique Bureau CABine) is a semi-continuous system based on wayside transponders which transmit to trains information for supervision of the braking curve (ATP = Automatic Train Protection).

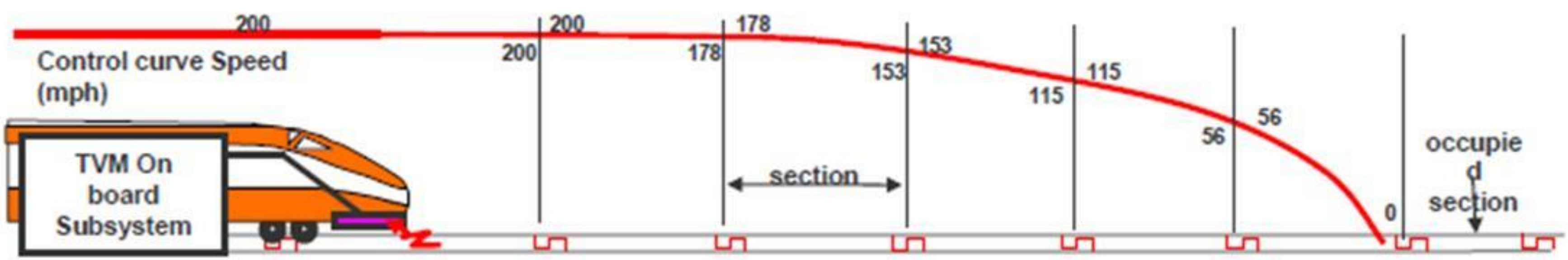
The French signalling system for HS lines: TVM (Transmission Voie Machine)

- Vital ATP (Automatic Train Protection) system with distribute architecture for speed up to 200 mph;
- Single Trackside Control Centers (TCC) located every about 9 miles;
- The system operates without trackside signalling;
- Continuous track-to-train transmission through track circuits.



The French signalling system for HS lines: TVM (Transmission Voie Machine)

- Continuous speed control, calculated on board for each block section and based on data received from trackside (section length, speeds at the beginning and at the end of the block section, slope);
- Audio Frequency Track Circuits:
- Other auxiliary transmission media (balises) needed to manage track conditions (Power supply, Tunnels, etc.).



On line Paris-Strasburg ERTMS L2 system has been implemented together with TVM national system

The Italian signalling system for HS lines

- **Speed up to 156.0 mph**

  Italian BACC (Blocco Automatico a Correnti Codificate) national light signals block system, based on coded track circuits and on board repetition of trackside light signals. These HS lines are also used by conventional trains (to be soon upgraded to ERTMS);

- **Speed up to 187.5 mph**

  ERTMS (European Rail Traffic Management System) level 2. In the Italian application ERTMS operates without overlapping on other systems and without trackside signals.

  Only ERTMS equipped trains can run on such HS lines. The lack of a back-up system (ERTMS level 1 or similar) is balanced by a very high level of redundancy of subsystems involved.

Why ERTMS?

1. **Interoperability**: European Commission supports the development of operational and technical interoperability with unified signalling equipment in order to open railway markets to all train operators;
2. **Safety**: ERTMS equipments are designed and produced in compliance with CENELEC standards;
3. **Performance**: high speed can be reached using the lowest amount of time distance between the trains (in Italy only 2’30” between two trains running at 187.5 mph);
4. **Availability/Reliability**: due to the particular ERTMS architecture, there are less equipments along the lines, reducing fault probability and improving system reliability.

ERTMS levels

- ERTMS Level 1:

  Overlay using Eurobalises and track side signals;

- ERTMS Level 2:

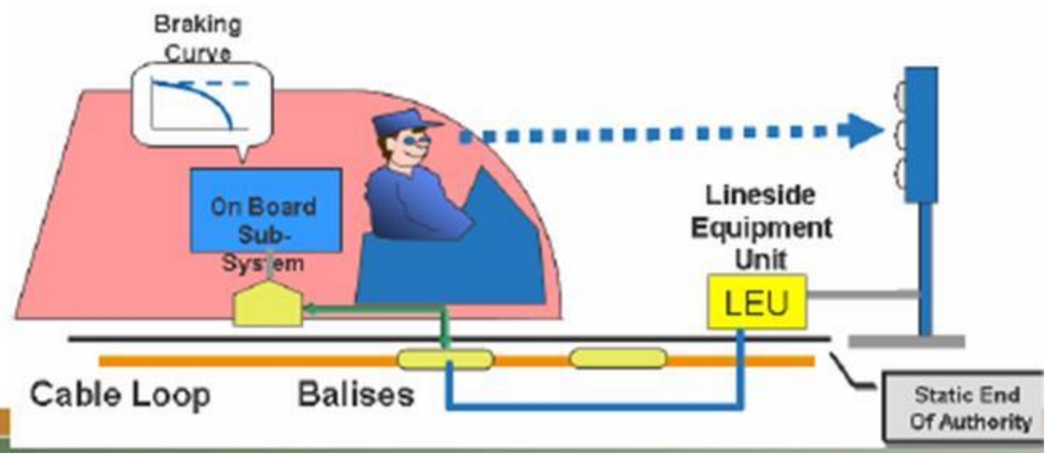
  Fixed Block Authority is communicated directly from the Radio Block Center (RBC) to the train using GSM-R. Wayside track signals are optionally required;

- ERTMS Level 3:

  Introduction of "moving block". Wayside track signals are not required.

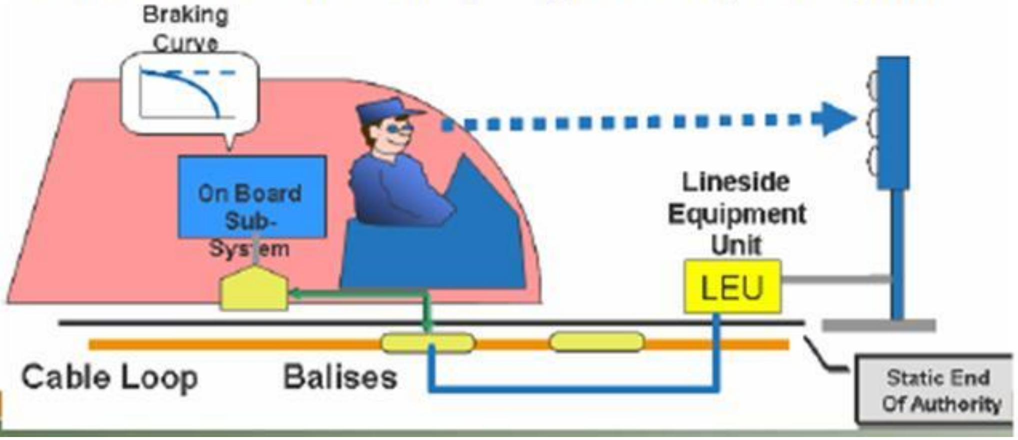
Which ERTMS? ERTMS level 1

- Discontinuous system working on an underlying and already existing signalling system; provides a continuous speed supervision;
- Movement authorities and track description data are generated by electronic Lineside Equipment Unit (LEU), located by side of the tracks, on the basis of information received from external signalling systems and track circuits;



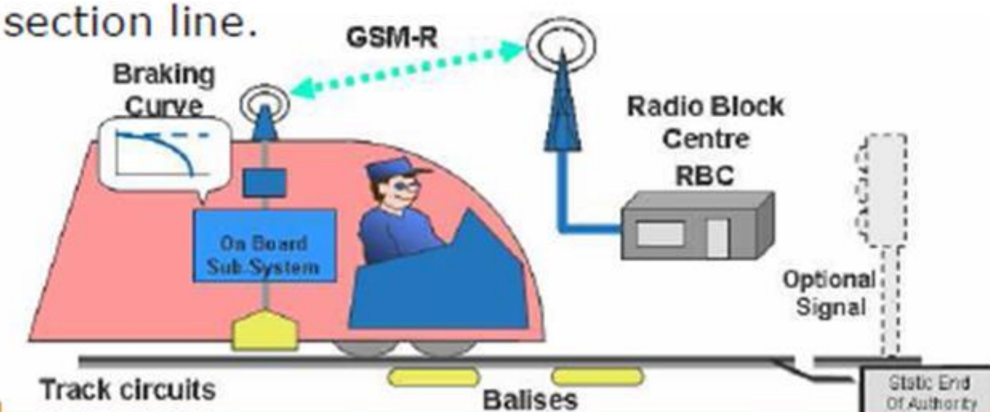
Which ERTMS? ERTMS level 1

- Movement authorities are transmitted to the train via wayside equipments called balises;
- The on-board sub-system calculates a dynamic speed profile taking into account the train braking characteristics and commands the brake application if necessary;
- Lineside signals are required. Loop (cable or radio) could be used in order to immediately refresh information related to the clear signal aspect (infill function).



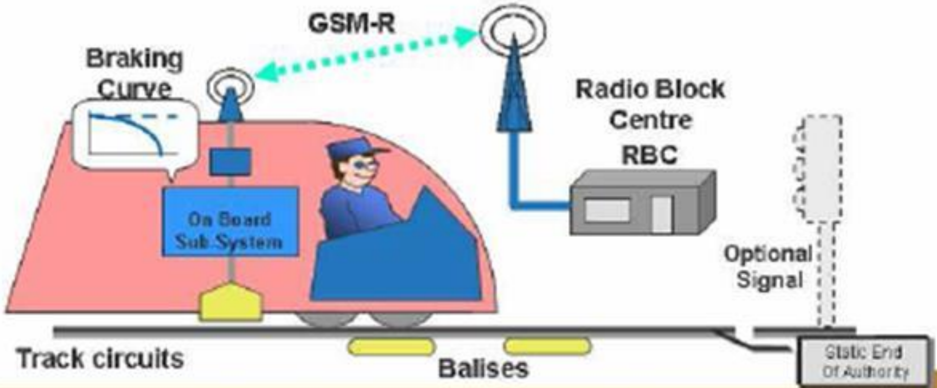
Which ERTMS? ERTMS level 2

- Radio based Automatic Train Control (ATC) system (working on optional signalling system), which provides a continuous speed supervision toward fixed points of the line (end of block sections, speed restrictions, etc.);
- Movement Authorities, track description data, temporary speed restrictions and emergency messages are generated by Radio Block Centre (RBC) on the basis of information received from train itself, external interlocking system and track circuit. A RBC usually manages about 62 miles of double track section line.



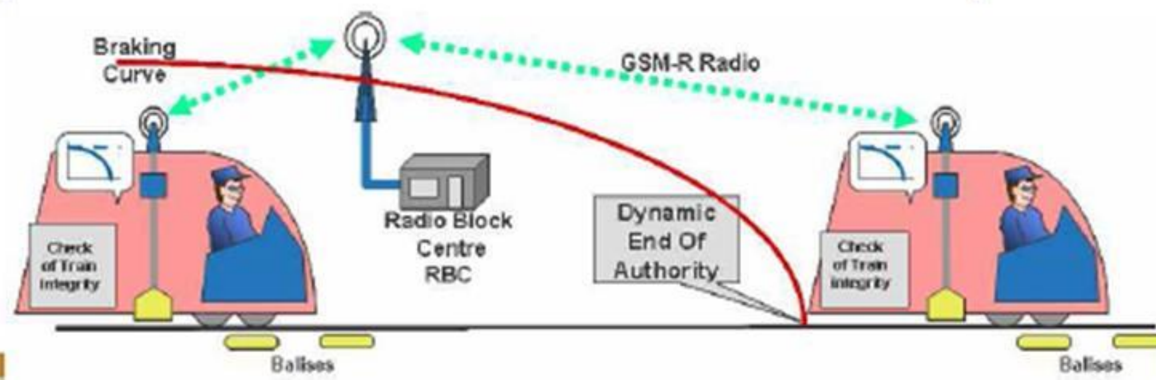
Which ERTMS? ERTMS level 2

- Messages are transmitted/received to/from the train via GSMR system;
- Balises are used mainly for spot transmission of train location reference, to manage hand-over between RBCs and other particular situations;
- The on-board sub-system calculates a dynamic speed profile taking into account the train braking characteristics and commands the brake application if necessary;
- Lineside signals are optional.



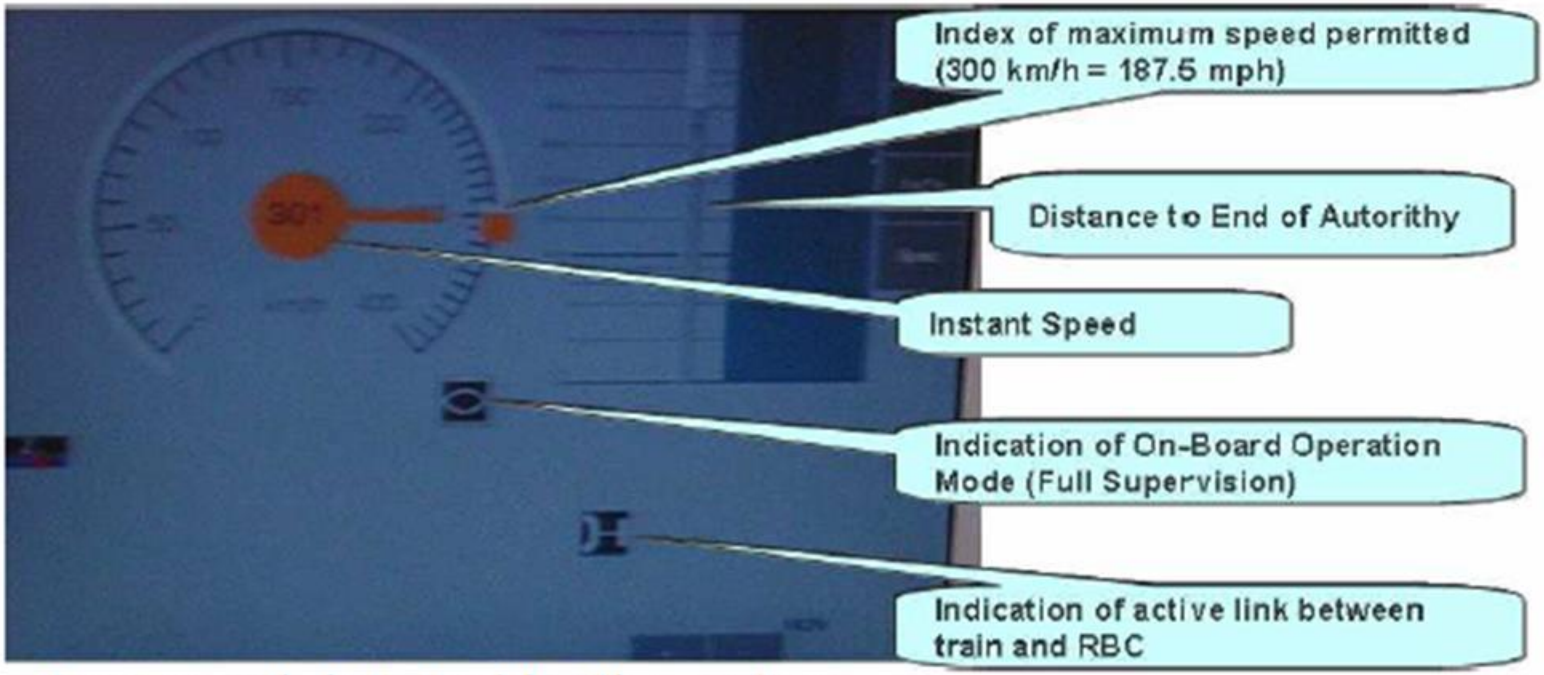
Which ERTMS? ERTMS level 3

- Main features similar to ERTMS level 2, except for:
  - ✓ Functional difference: the target is the end of the preceding train (moving block);
  - ✓ Technical differences:
    - On-board equipment to check the train integrity is required (RBC needs this information to calculate movement authority);
    - Track Circuit for train detection are not required.
- Performances:
  - ✓ Increase line capacity (relevant for lines with intense traffic at low speed as subway)



ERTMS On Board MMI

The on board computer calculates the maximum permissible speed, monitors the real speed and controls the driver's indicators



Over speed detected by the system

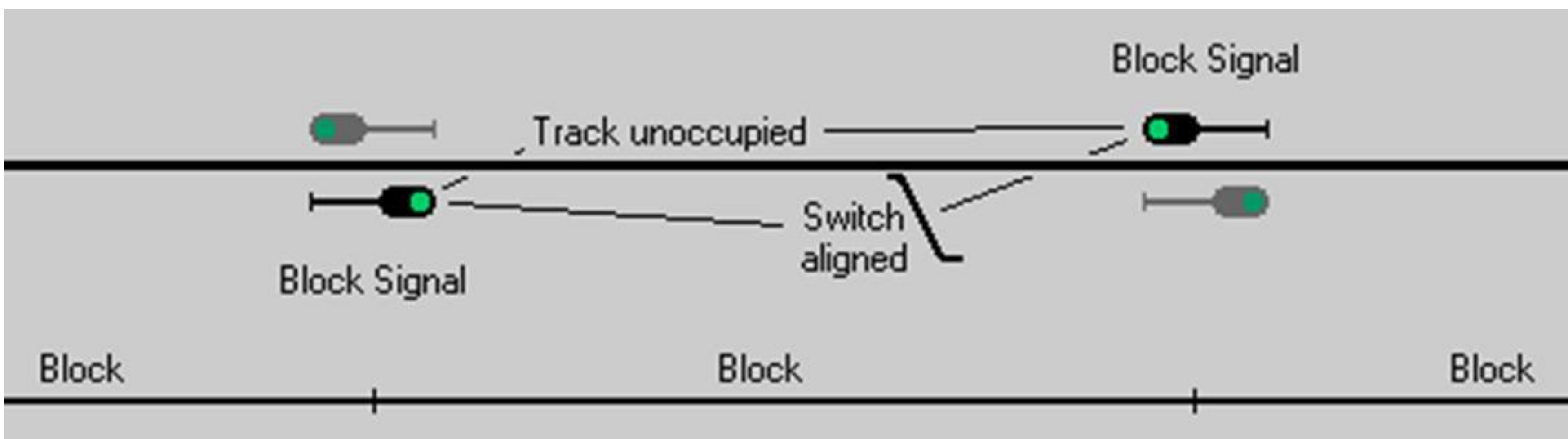
Route Setting and Central Train Control

Outline

- Automatic Block Signaling
- Interlocking
- Traffic Control System
- Centralized Traffic Control

Automatic Block Signaling

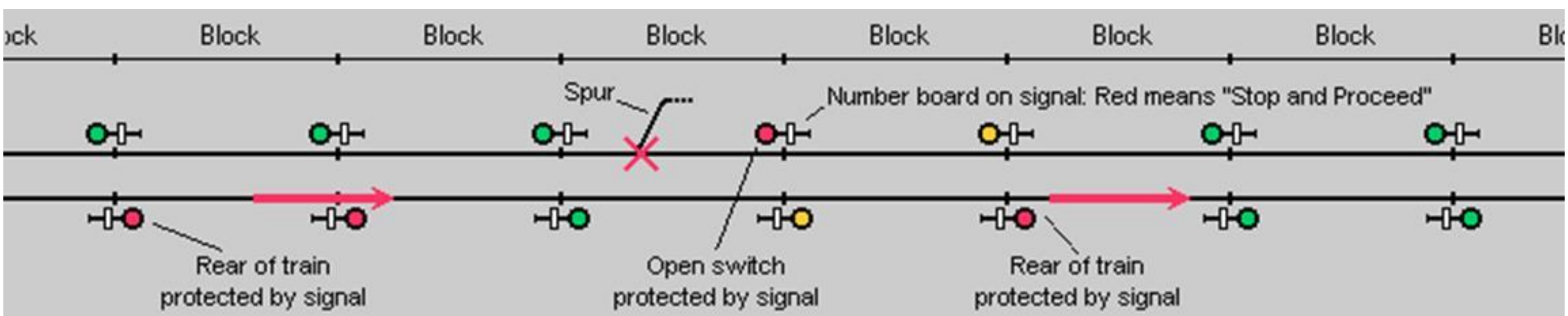
- All switches in the block are properly aligned for the main track
- The block is free of other trains
- Restrictive signal aspects are displayed so that safe braking distances are ensured if two trains attempt to enter the same



- blockhttp://www.lundsten.dk/us_signaling/signalbasics/

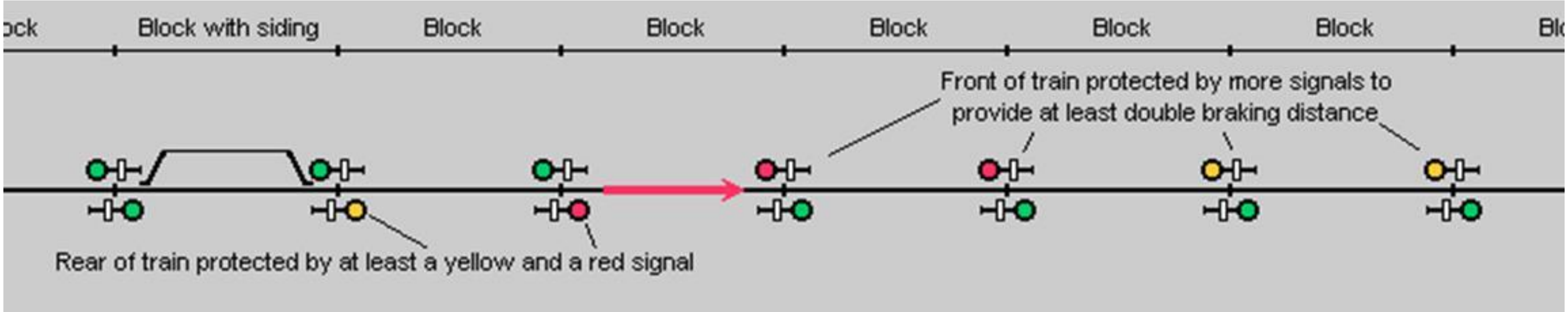
Double Track ABS

- On lines with 2 tracks, each track can be assigned a fixed direction of travel, the so called Current of Traffic.
- Each track will only be signaled for trains moving With the Current of Traffic
- A (rare) movement Against the Current of Traffic will have to have "manual" authorization.



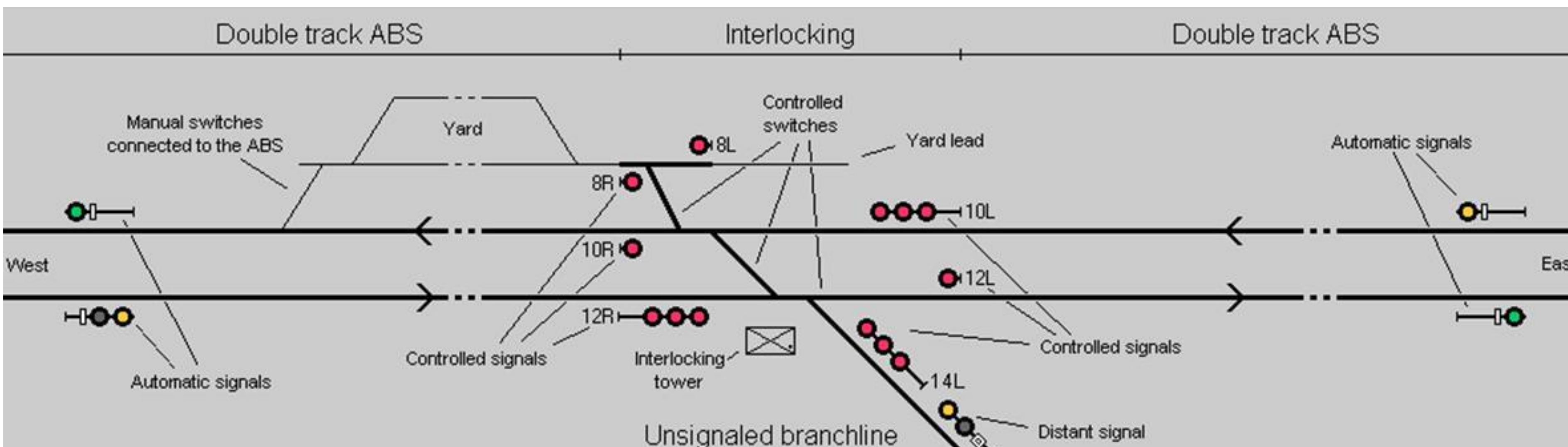
Single Track ABS

- For opposing trains, however, the ABS must additionally provide a safety zone against head-on collisions



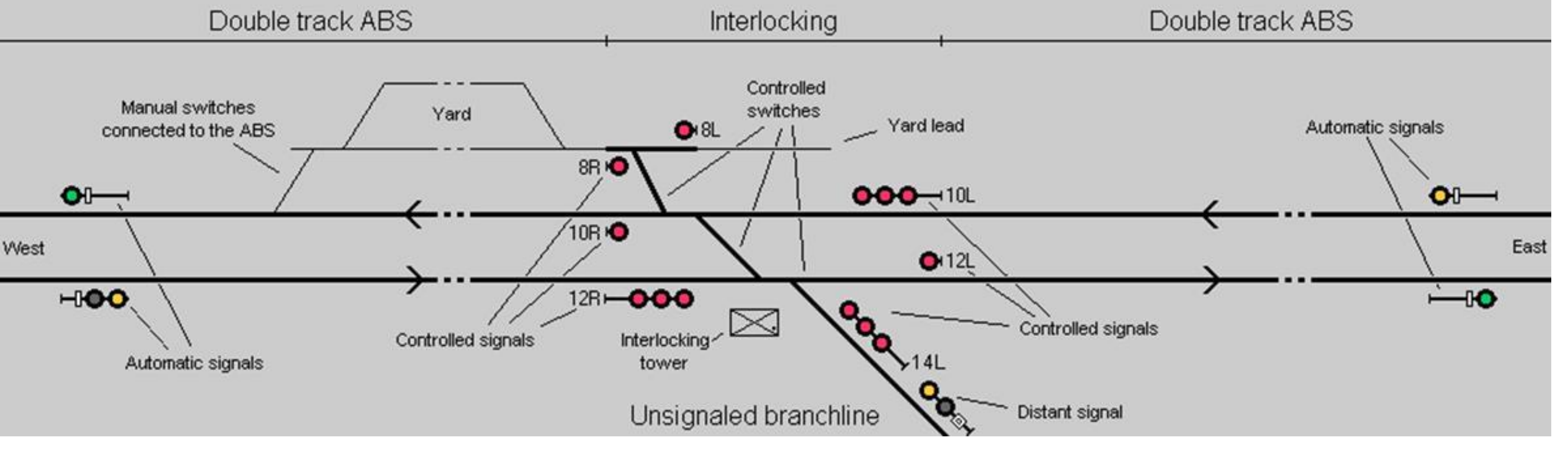
Interlocking

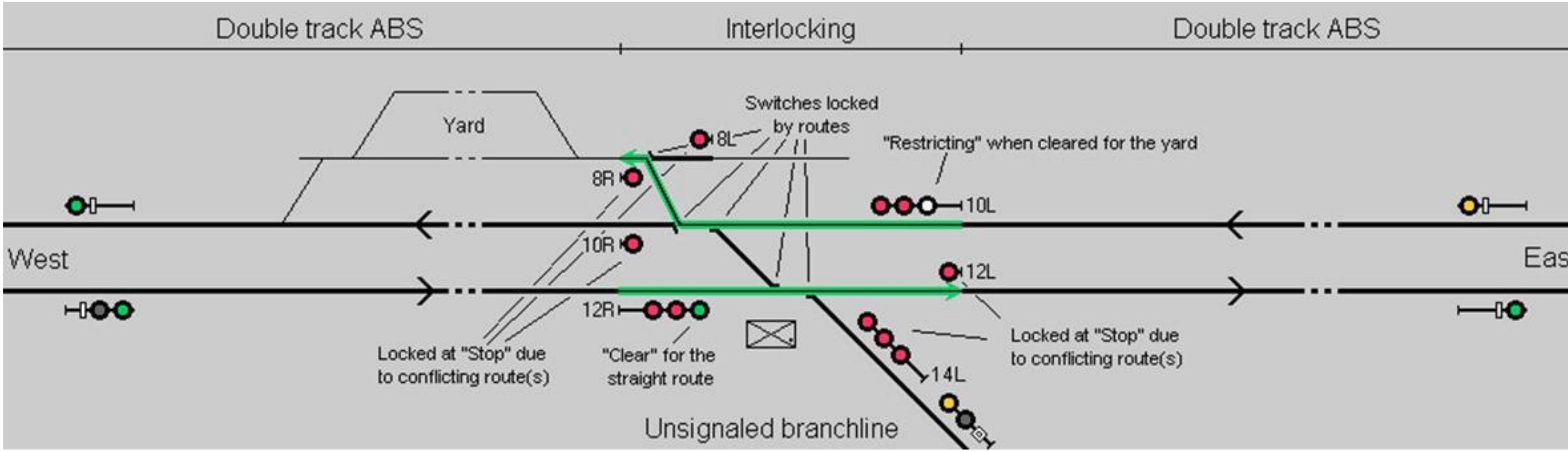
- An interlocking typically controls a number of power controlled switches, and allows trains to move from one main track to another, enter or exit sidings, yards etc.



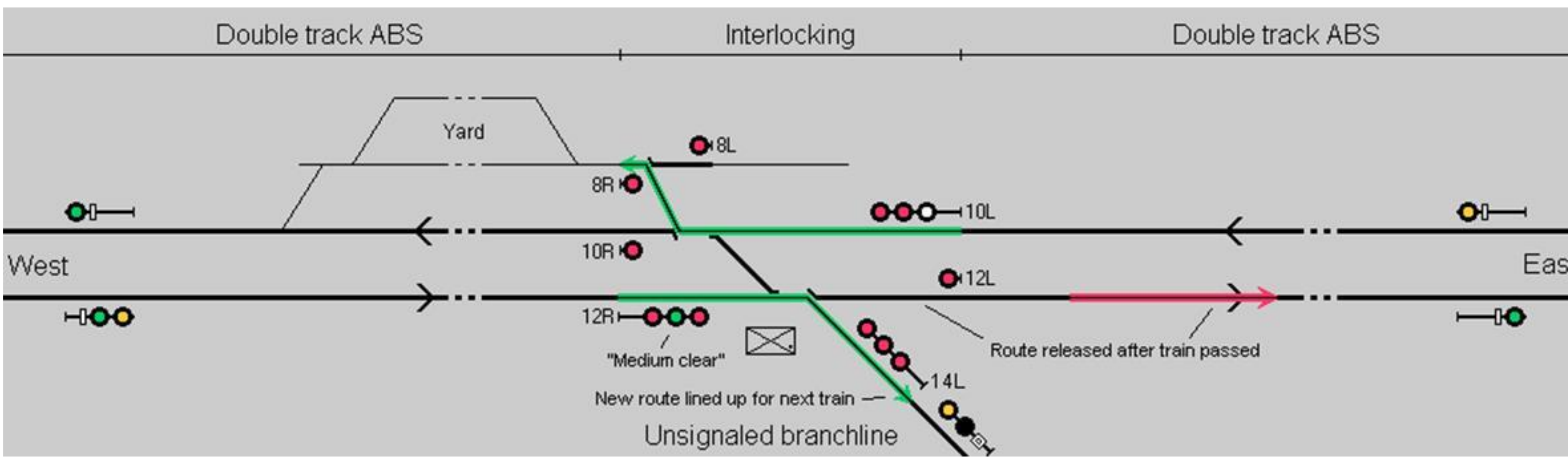
Interlocking

- Signals cannot display a permissive aspect unless switches are aligned properly for the train move
- Signals cannot simultaneously display proceed aspects for conflicting train moves





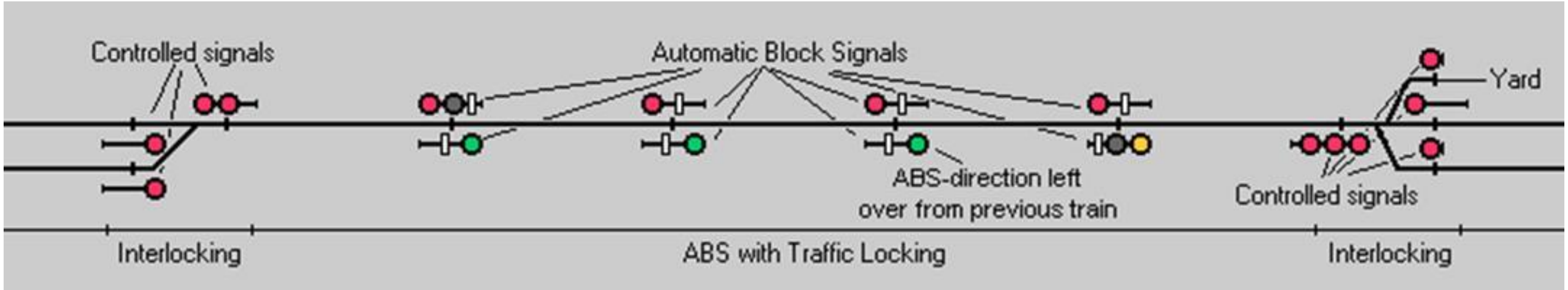
Double track ABS
Interlocking
Double track ABS
Yard
Switches locked
by routes
8L
8R
"Restricting" when cleared for the yard
10L
West
10R
East
12L
12R
Locked at "Stop" due
to conflicting route(s)
"Clear" for the
straight route
Locked at "Stop" due
to conflicting route(s)
14L
Unsignaled branchline

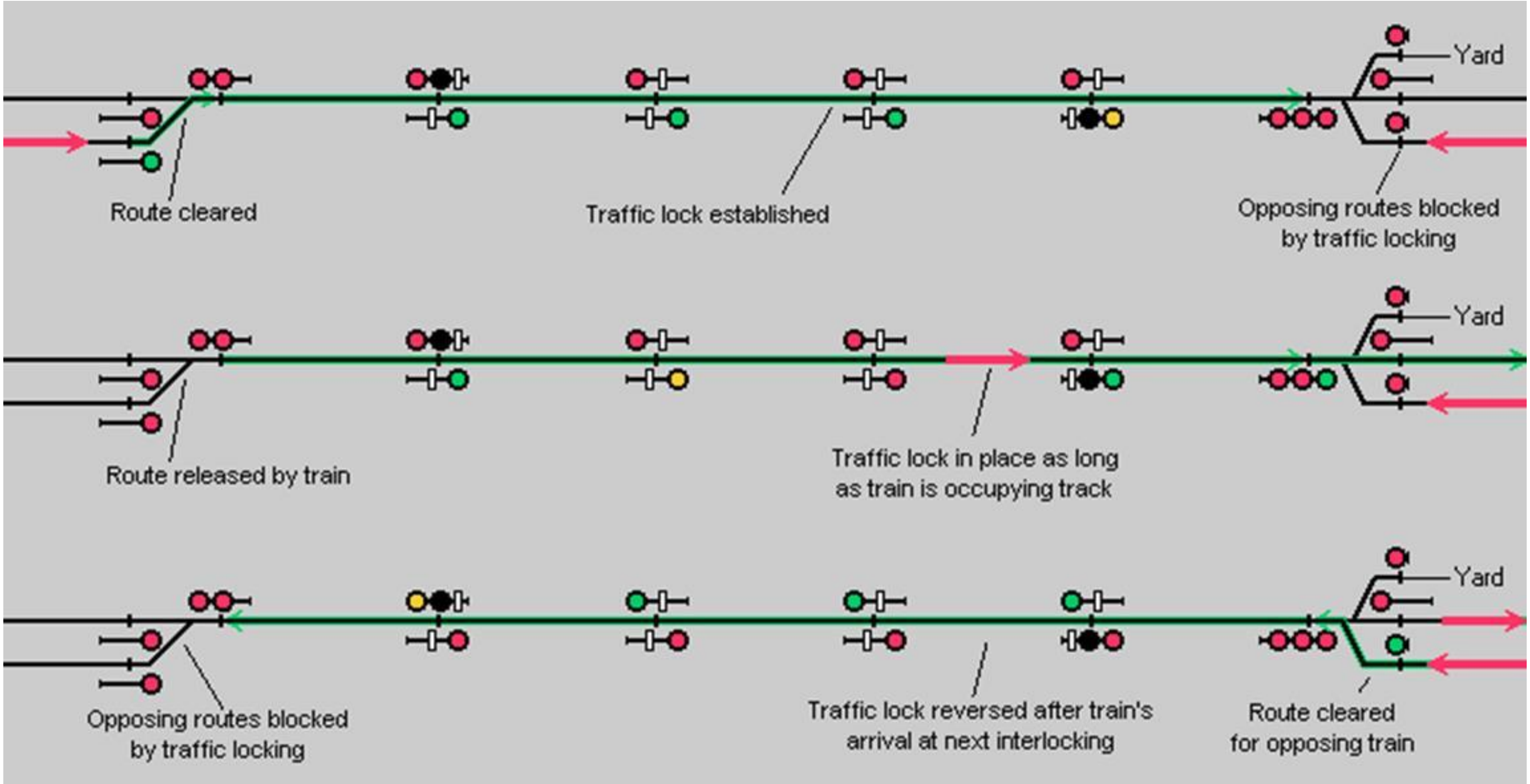


Double track ABS
Interlocking
Double track ABS
Yard
8L
8R
10L
West
10R
East
12L
12R
"Medium clear"
Route released after train passed
14L
New route lined up for next train
Unsignaled branchline

Traffic Control System

- Traffic locking locks the direction of travel in a track when an interlocking clears a signal to that track
- It prevents the interlocking in the other end of the track from sending trains onto that track.

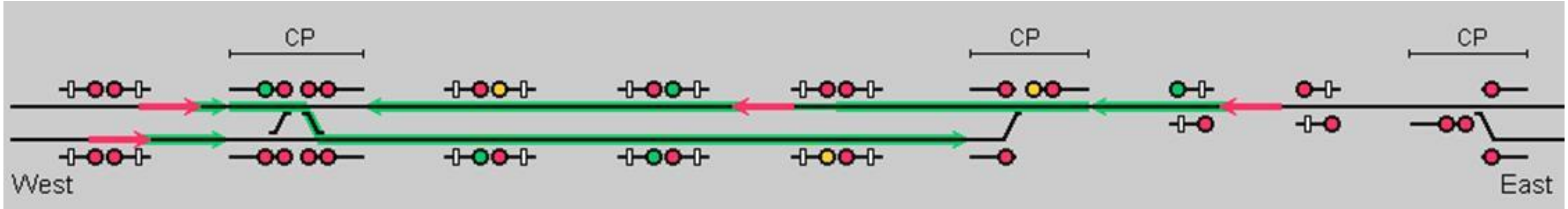




Yard
Route cleared
Traffic lock established
Opposing routes blocked by traffic locking
Yard
Route released by train
Traffic lock in place as long as train is occupying track
Yard
Opposing routes blocked by traffic locking
Traffic lock reversed after train's arrival at next interlocking
Route cleared for opposing train

Centralized Traffic Control

- Allows remote control of a Traffic Control System



Interlocking in HSR

- Integrated interlocking and control
- Integrated station and block
  - Block used as unit
  - No separation between station interlocking and blocking

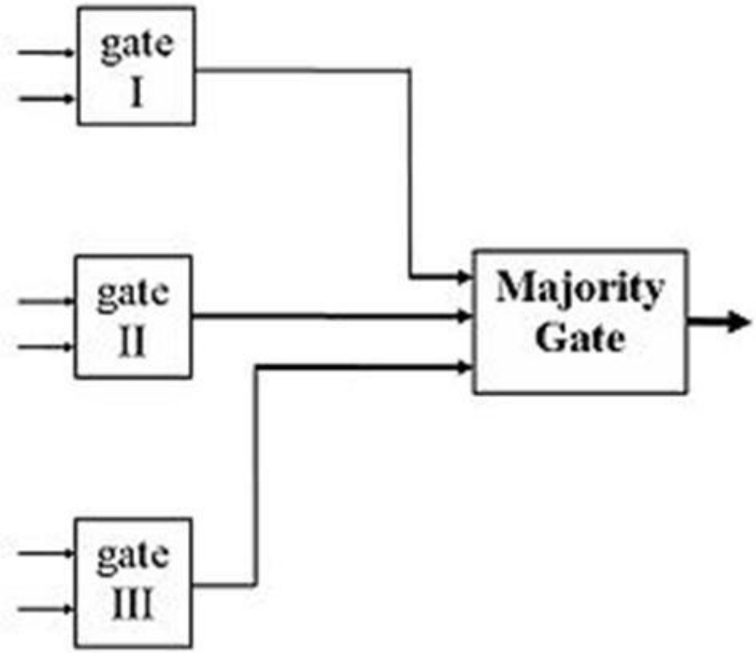
Characteristics of interlocking in HSR

- Integrated system
- Division based, not station based
- Hardware redundancy system for system reliability
- Automatic route setting and route storage
- Electronic interlocking
- Human-machine interface improvement based on multimedia
- Use maintenance management center

Interlocking - redundancy

- In computer science, there are four major forms of redundancy:
  - Hardware redundancy, such as DMR and TMR
  - Information redundancy, such as error detection and correction methods
  - Time redundancy, performing the same operation multiple times such as multiple executions of a program or multiple copies of data transmitted
  - Software redundancy such as N-version programming

Triple modular redundancy



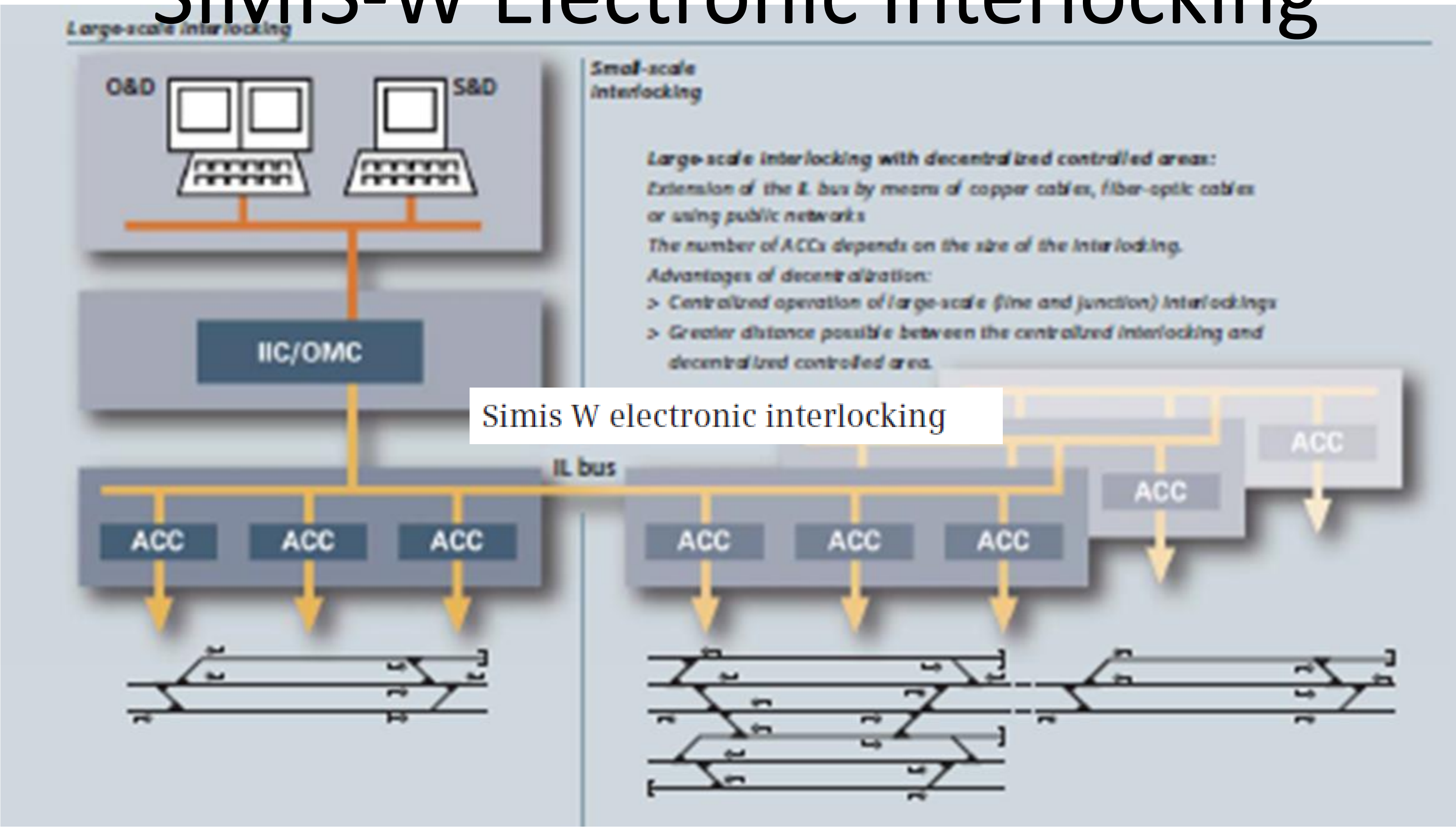
- http://en.wikipedia.org/wiki/Triple_modular_redundancy

- 2 out of 3 redundancy
- 3 out of 4 redundancy

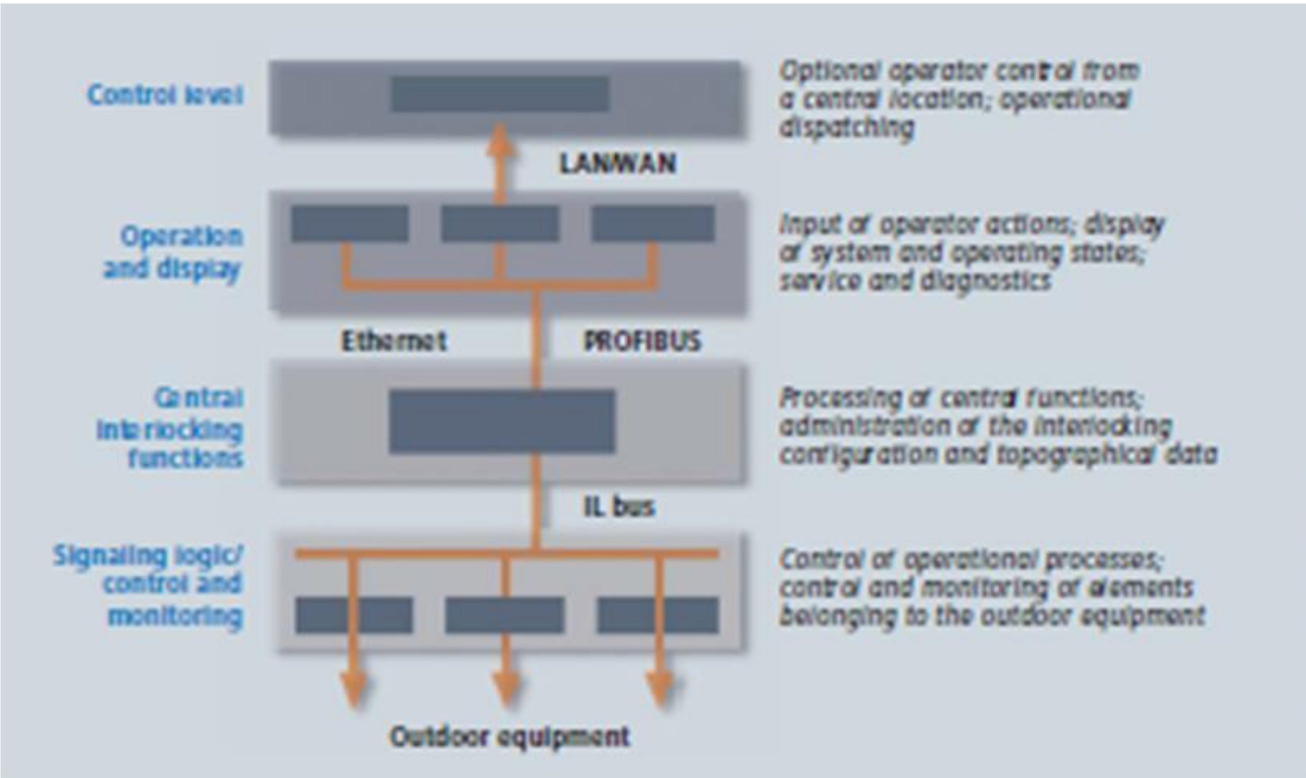
Typical interlocking systems

- SIMIS (Siemens)
- TVM430 for TGV
  - https://www.youtube.com/watch?v=xRKC6N5MAjc
- SPAC-8 (Japan)

SIMIS-W Electronic Interlocking



Simis W electronic interlocking



Control level
Optional operator control from a central location; operational dispatching
LAN/WAN
Operation and display
Input of operator actions; display of system and operating states; service and diagnostics
Ethernet
PROFIBUS
Central interlocking functions
Processing of central functions; administration of the interlocking configuration and topographical data
IL bus
Signaling logic/ control and monitoring
Control of operational processes; control and monitoring of elements belonging to the outdoor equipment
Outdoor equipment

Centralized traffic control for HSR

- Functions
  - Dispatching: display train status in real time, automatically send route setting command to station, run train adhering to schedule
  - Passenger service
  - Engine and car dispatching
  - Maintenance dispatching
  - Electricity power dispatching
  - Signal equipment monitoring

Centralized Traffic Control

- http://en.wikipedia.org/wiki/Centralized_traffic_control

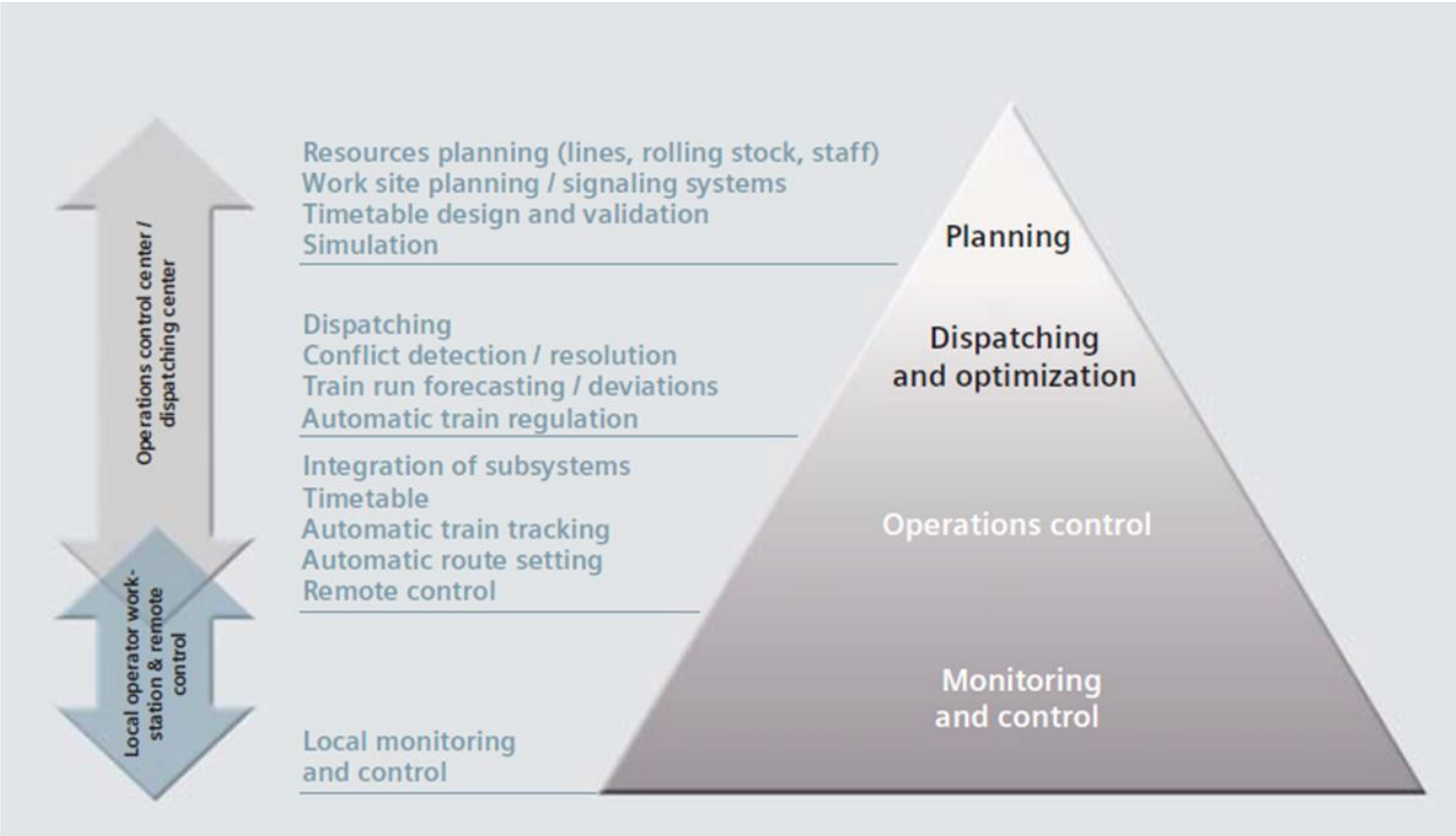
Typical systems in the world

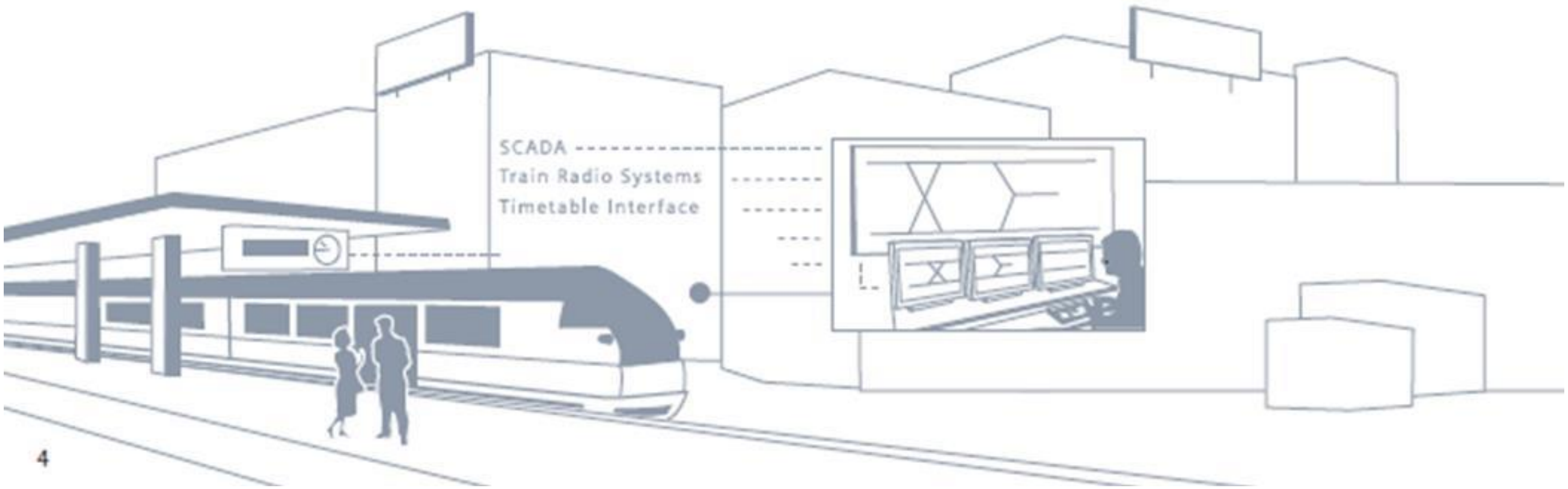
- Vicos OC 501 (Siemens)
- Alstom ICONIS ATS
- COSMOS (computerized, safety, maintenance and operation system, Japan)

Vicos OC 501

- Centralised operation of the interlocking, train operation control, and the display of all train operations on the operator consoles through a network of computers and automation functions
- In addition to electronic interlockings, relay interlockings can also be incorporated into centralised operations control via a remote control system
- Train identification, passenger information, and building services automation systems ran also be connected
- A modular operating control system: several computers are used for the various sub-tasks. This ensures that the large amount of data arriving from the various interlockings and other connected systems are processed on time.
- Suitable for all types of railways ranging from light rail and metros to regional, industrial, and mainline networks
- Make use of existing resources.

Vicos OC 501 (Siemens)




SCADA
Train Radio Systems
Timetable Interface

Owing to its modularity and flexibility, it is possible to tailor it to the individual needs of railway operators as well as the environmental conditions.

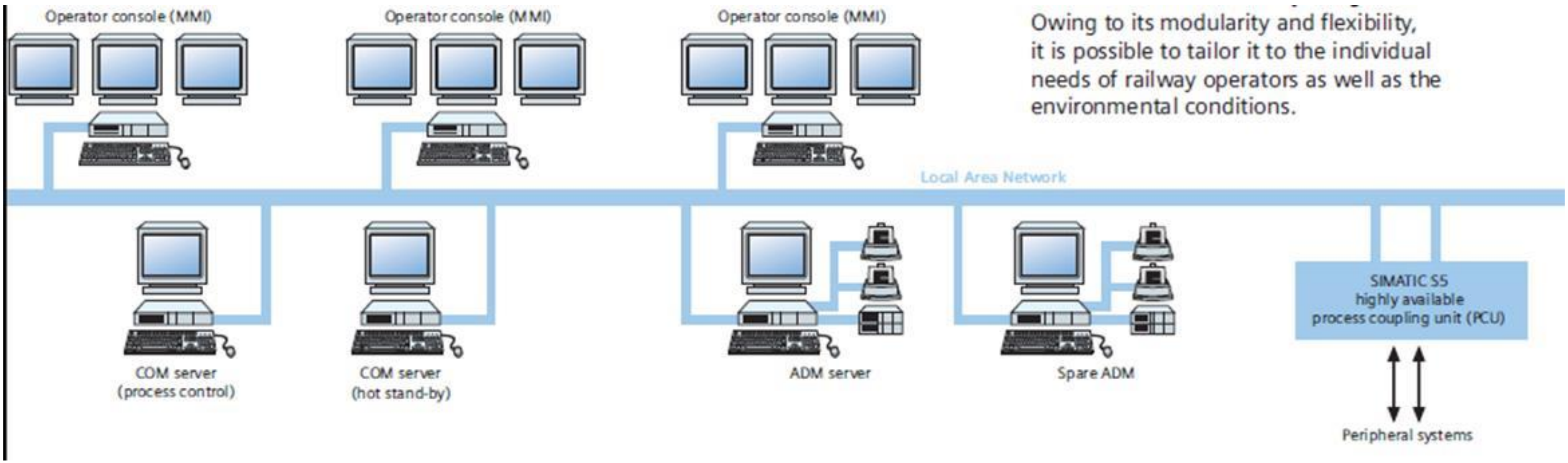
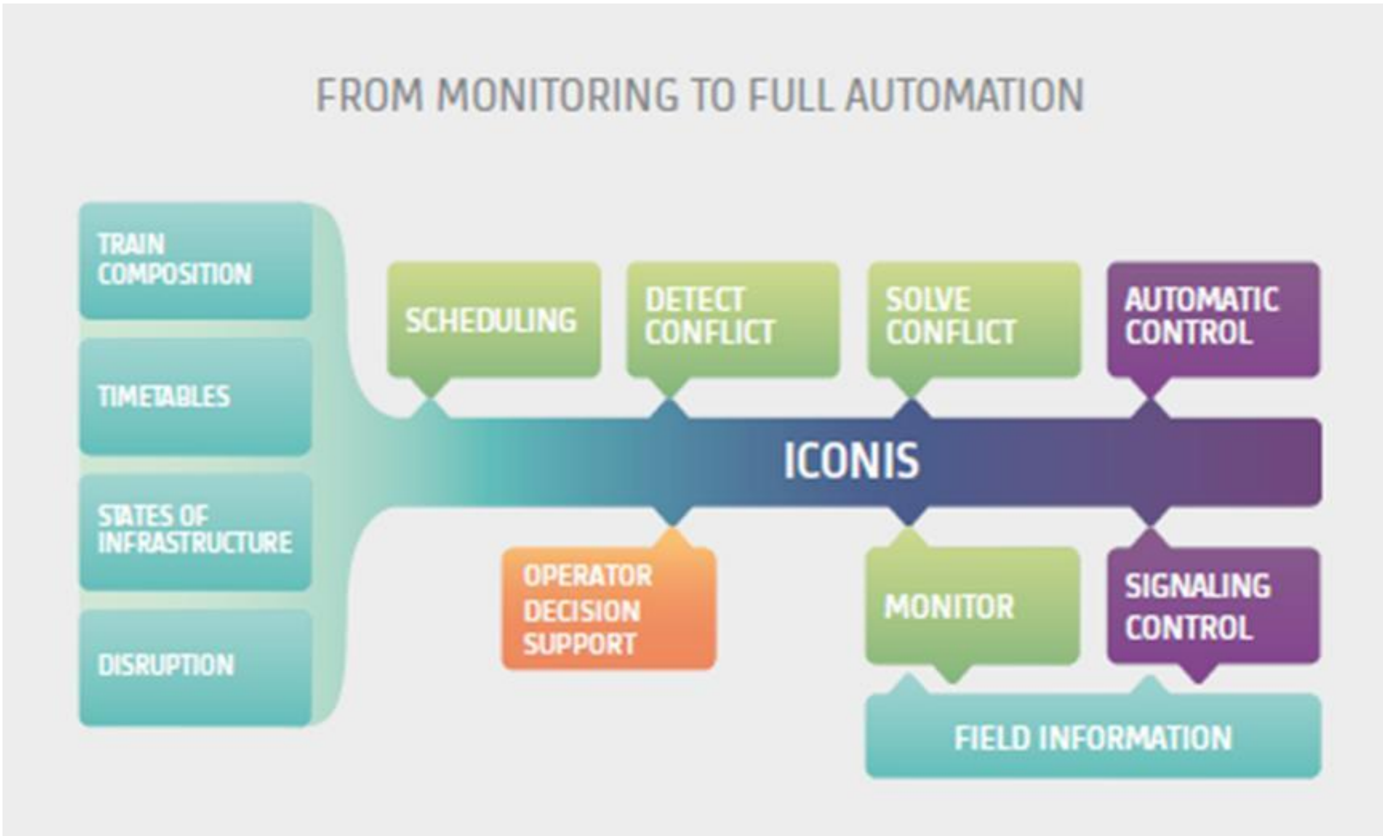


Рис. 5. Рабочее место диспетчера (фото: Siemens)

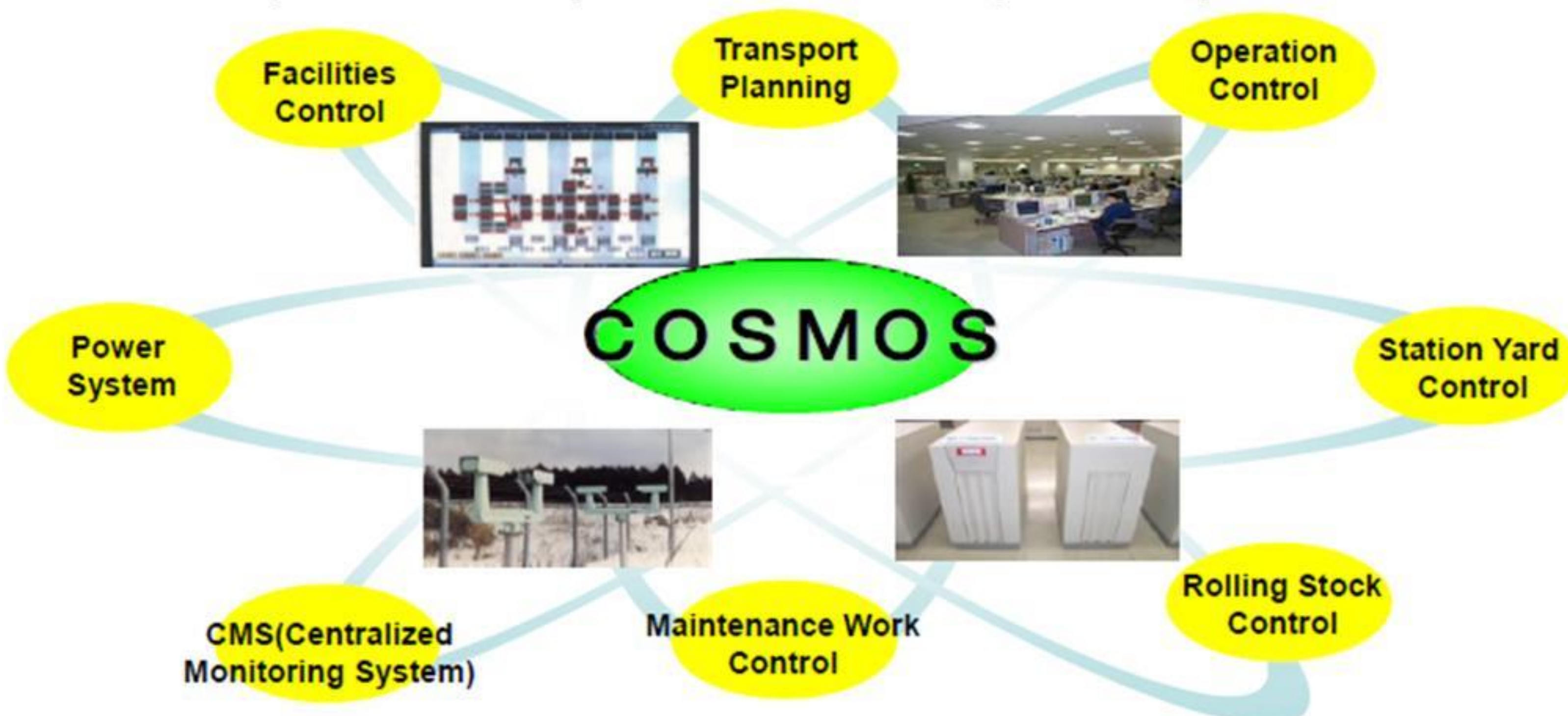
Alstom ICONIS ATS



COSMOS

Integrated Intelligent Transport Management System

COSMOS: Computerized Safety, Maintenance and Operation Systems of Shinkansen



Communications for HSR

Communications and Signals:Then and Now

- http://www.youtube.com/watch?v=3Sow8O1_ZNA

Communication Needs

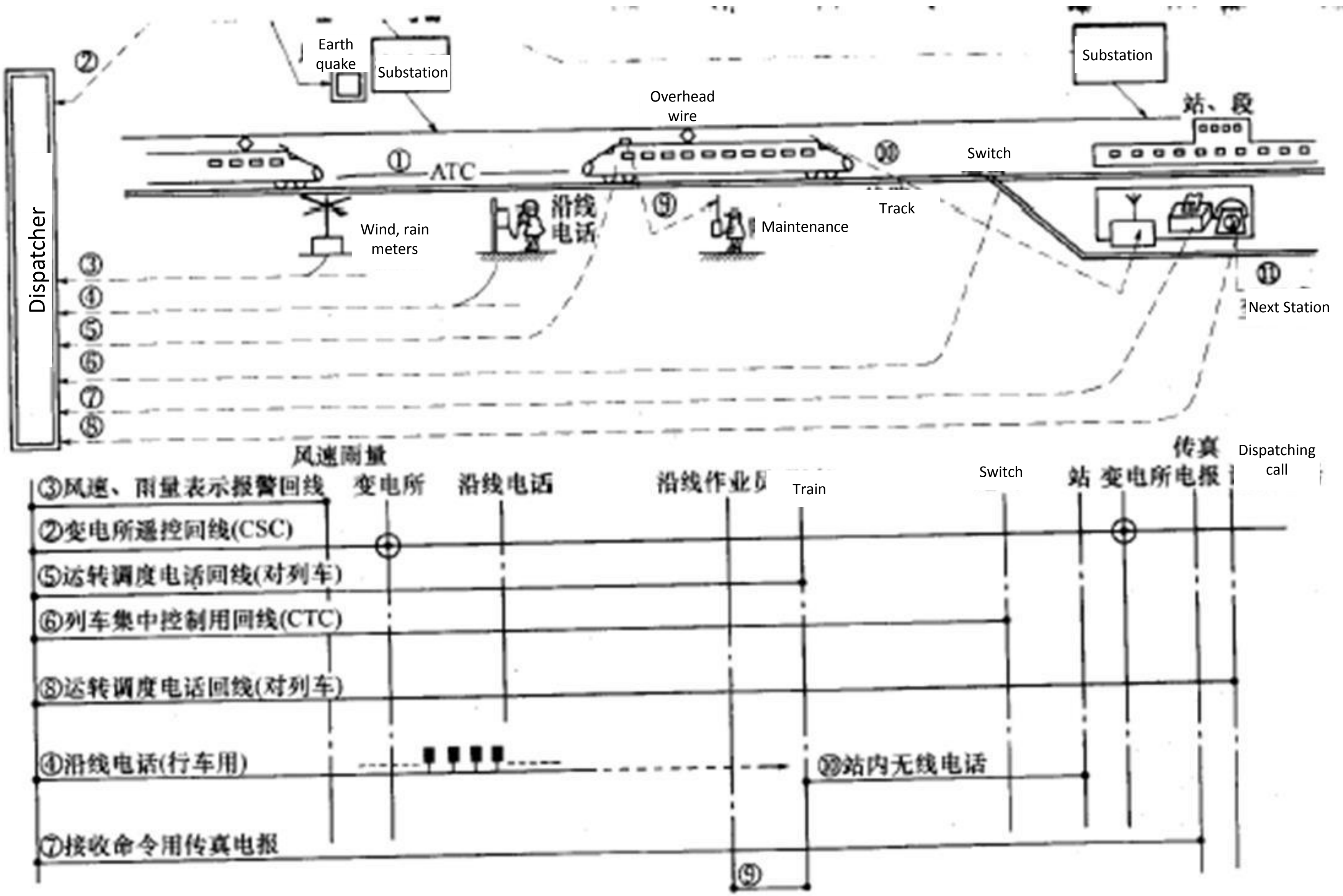
- Dispatching command transmission
- Passenger service: real time information provision and offline statistics
- Maintenance and train service

Communication requirements

- Reliable
- Efficiency
- Integrated signal and communications
- Integrated computer and its network
- Multiple types of information to transmit: data, voice, image, monitoring signal, etc.
- Multiple media: wireline and wireless

Communications in Shinkansen

- Rail operation safety and efficiency
  - ATC: circuit and cable
  - CSC: substation remote control
  - Wind speed, rain fall monitoring
  - Track side telephone for maintenance
  - Train driver and dispatching operator wireless communications
  - CTC: dispatching center and 26 signal stations transmitting information to set routes
  - Fax from dispatching center to stations
  - Telephone from dispatching center to stations
  - Maintenance worker track side safety protection wireless device
  - Blocking telepone



Earth quake
Substation
Overhead wire
Substation
站、段
①ATC
⑩
Switch
Track
Wind, rain meters
沿线电话
⑨
Maintenance
Dispatcher
②
③
④
⑤
⑥
⑦
⑧
⑪
Next Station
风速雨量
③风速、雨量表示报警回线
变电所
沿线电话
Train
Switch
站
变电所
传真电报
Dispatching call
②变电所遥控回线(CSC)
⑤运转调度电话回线(对列车)
⑥列车集中控制用回线(CTC)
⑧运转调度电话回线(对列车)
④沿线电话(行车用)
⑩站内无线电话
⑦接收命令用传真电报
⑨

Communications in Shinkansen (cont.)

- Communications for passenger service
  - Ticket booking
  - Station passenger information: arrival and dispatching time
  - Train operator communicating with dispatching
  - Passenger dispatchers
  - Fax into stations from dispatching center
  - Public telephone on train

Communications in Shinkansen (cont.)

- Communications for maintenance
  - Wireless mobile phone
  - Wireless call to maintenance crew from dispatching center
  - Direct phone between maintenance, power, and signal units
  - Track side phone
  - Fax

Communications - type

- Voice: direct phone, train phone, satellite (earth quake, etc.)
- Signal: blocking device, balise, highway and rail crossing, train dispatching, route setting
- Data: fax, ticketing
- Image

Communications - TGV

- Dispatching center to blocks
- Block warning
- Train to dispatching center
- Power facility maintenance to dispatching center

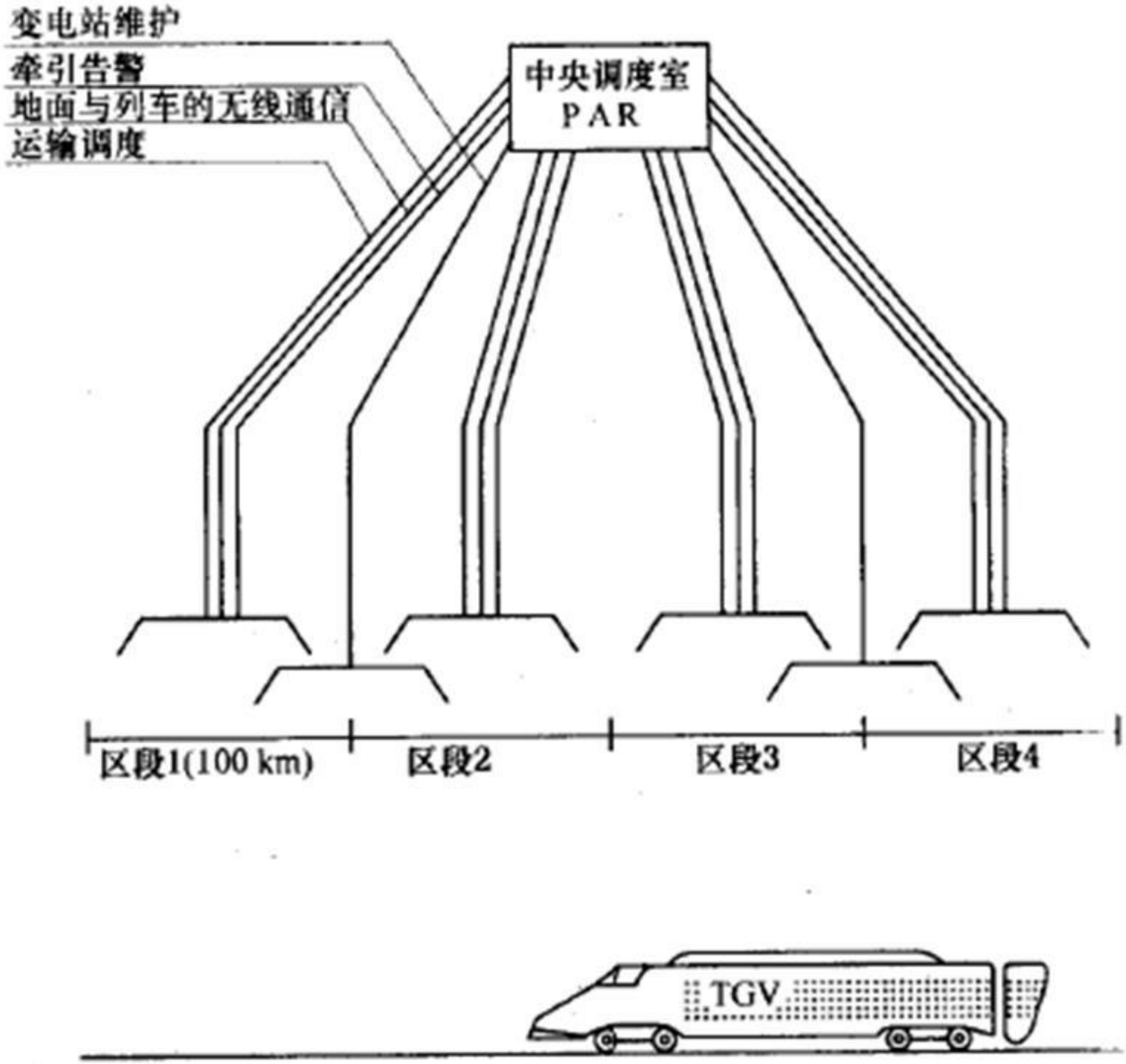


图 6-1-4　法国 TGV 专用通信简图

Wireline

- For mainline and interregional communication
- Telephone: cheap, track side maintenance
- Cable: short distance, power district, substation, ATC devices
- Composite cable: dispatching telephone, wireless station, and operators
- Fiber optical: data transmission,

Digital exchanger

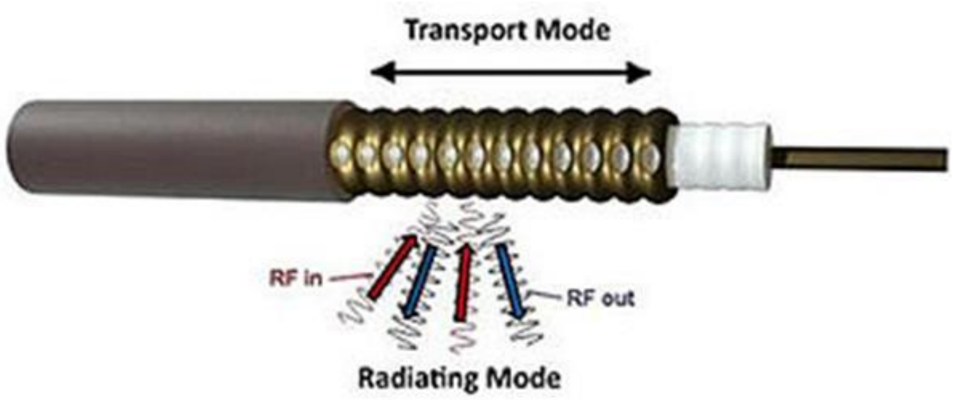
- Exchange from analog to digital signal for transmission

Wireless

- Fixed wireless communication：
  - Multi-channel microwave telecommunication
- Mobile wireless communications
  - Train wireless communications
  - Protection
  - Blocking
- Passenger mobile wireless communication
- satellite

Wireless (cont.)

- Train mobile communications
  - Leaky cable (Japan)
  - Fixed stations with wireless between stations (TGV)

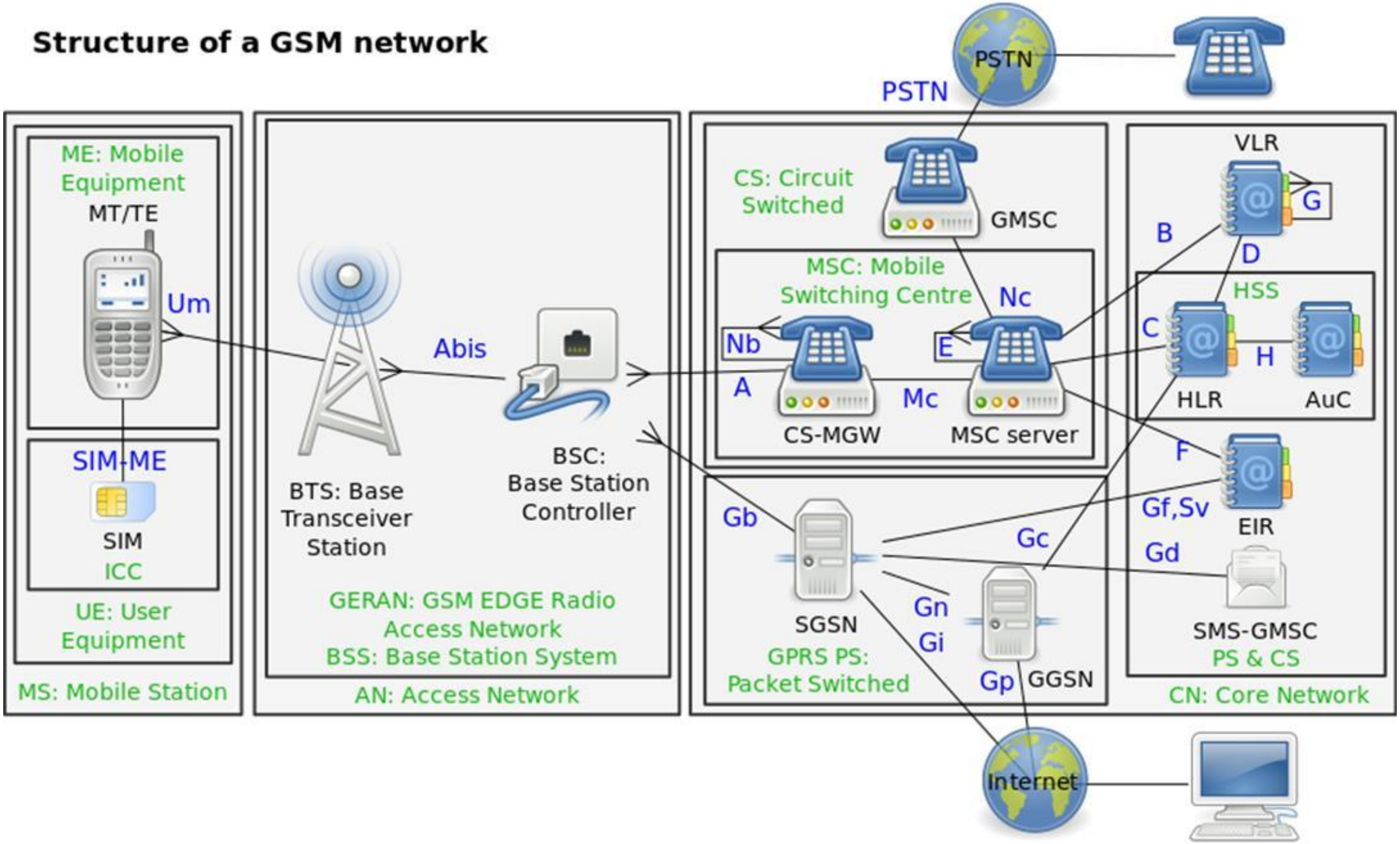


GSM-R, Global System for Mobile Communications – Railway

- It is used for communication between train and railway regulation control centres
- The system is based on GSM and EIRENE – MORANE specifications which guarantee performance at speeds up to 500 km/h (310 mph), without any communication loss.
- GSM is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second-generation (2G) **digital cellular networks** used by mobile phones

- http://en.wikipedia.org/wiki/GSM-R

GSM



- http://en.wikipedia.org/wiki/GSM

GSM-R

- GSM-R = GSM + voice dispatching + railroad application

- GSM-R transmitter mast on the Nuremberg–Ingolstadt high-speed railway line

GSM-R (cont.)

- GSM-R to replace existing incompatible in-track cable and analogue railway radio networks.
- The standard is to achieve interoperability using a single communication platform.
- GSM-R is part of the European Rail Traffic Management System (ERTMS) standard
- Carries the signaling information directly to the train driver, enabling higher train speeds and traffic density with a high level of safety

GSM-R (cont.)

- GSM-R is a secure platform for voice and data communication between railway operational staff, including drivers, dispatchers, shunting team members, train engineers, and station controllers.
- It delivers features such as group calls (VGCS), voice broadcast (VBS), location-based connections, and call pre-emption in case of an emergency.
- This will support applications such as cargo tracking, video surveillance in trains and at stations, and passenger information services.

GSM-R (cont.)

- Automatic train control
- Synchronizing engine control
- Efficient dispatching command transmission
- Train number transmission and train stop information transmission
- Train end air pressure return transmission

GSM-R (cont.)

- GSM-R is typically implemented using dedicated base station towers close to the railway.
- The distance between the base stations is 7–15 km. This creates a high degree of redundancy and higher availability and reliability.

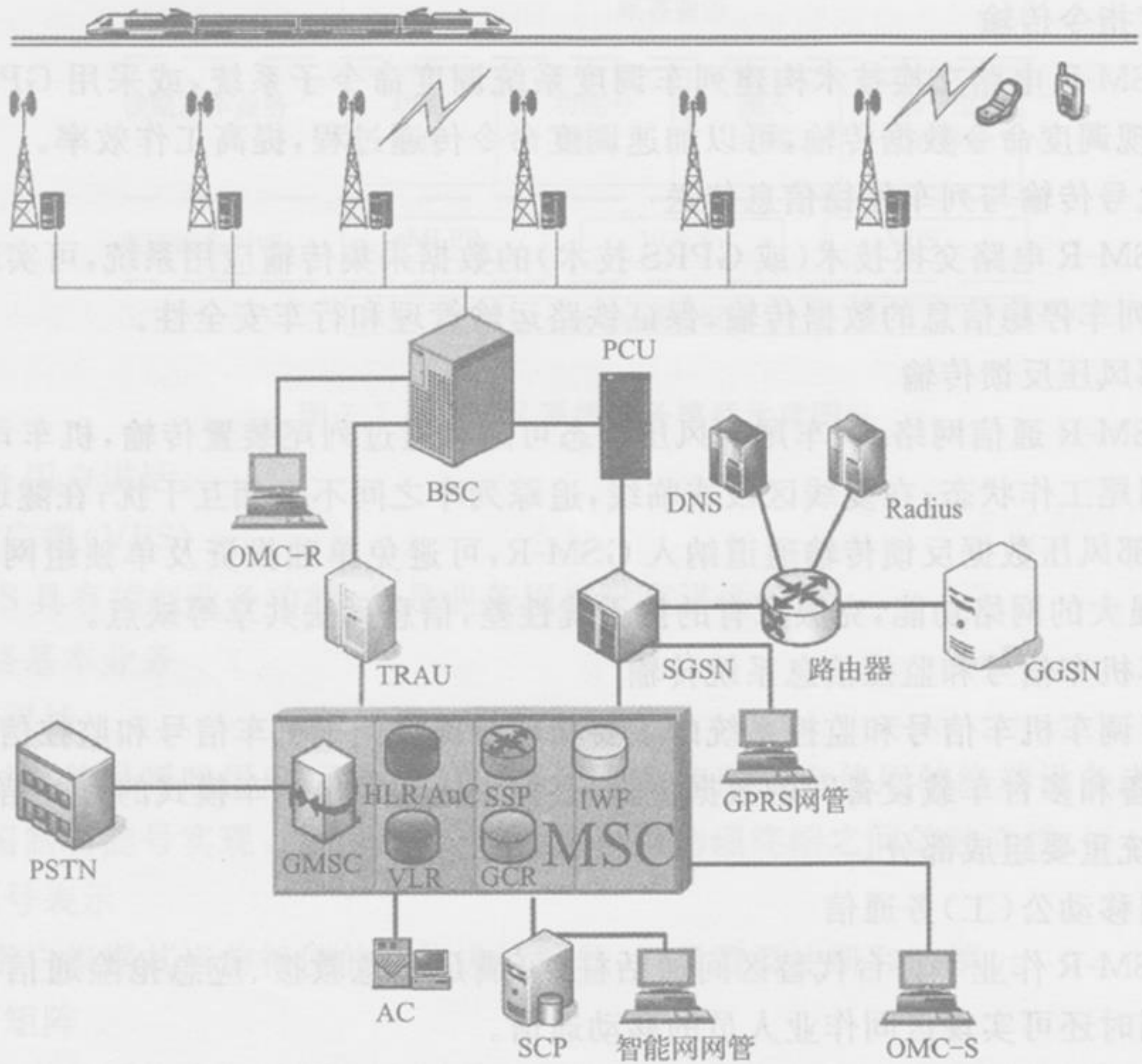


图 7.8　GSM-R 网络结构图

GSM-R (cont.)

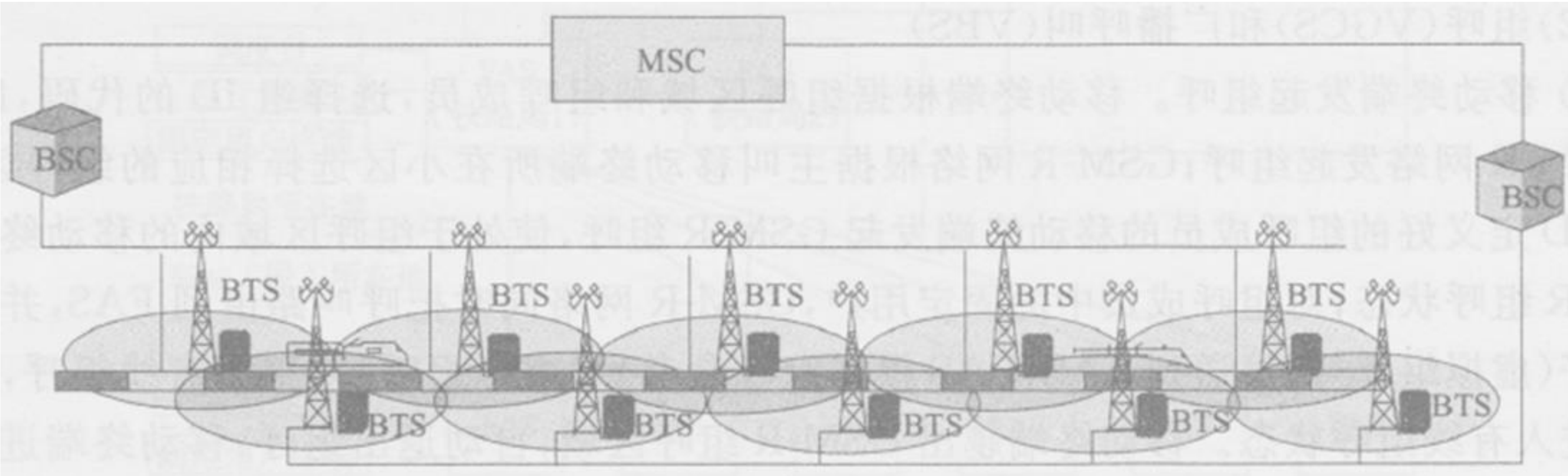
- The train maintains a circuit switched digital modem connection to the train control center at all times.
- This modem operates with higher priority than normal users (eMLPP). If the modem connection is lost, the train will automatically stop.

GSM-R (cont.)

- It is used to transmit data between trains and railway regulation centers.
- When the train passes over a **Eurobalise**, it transmits its new position and its speed, then it receives back agreement (or disagreement) to enter the next track and its new maximum speed. In addition, trackside signals become redundant.

System components

- Base station subsystem
- Network and switching subsystem
- General packet radio service
- Intelligent network
- Operation maintenance subsystem
- Terminal computer



MSC
BSC
BSC
BTS
BTS
BTS
BTS
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BTS
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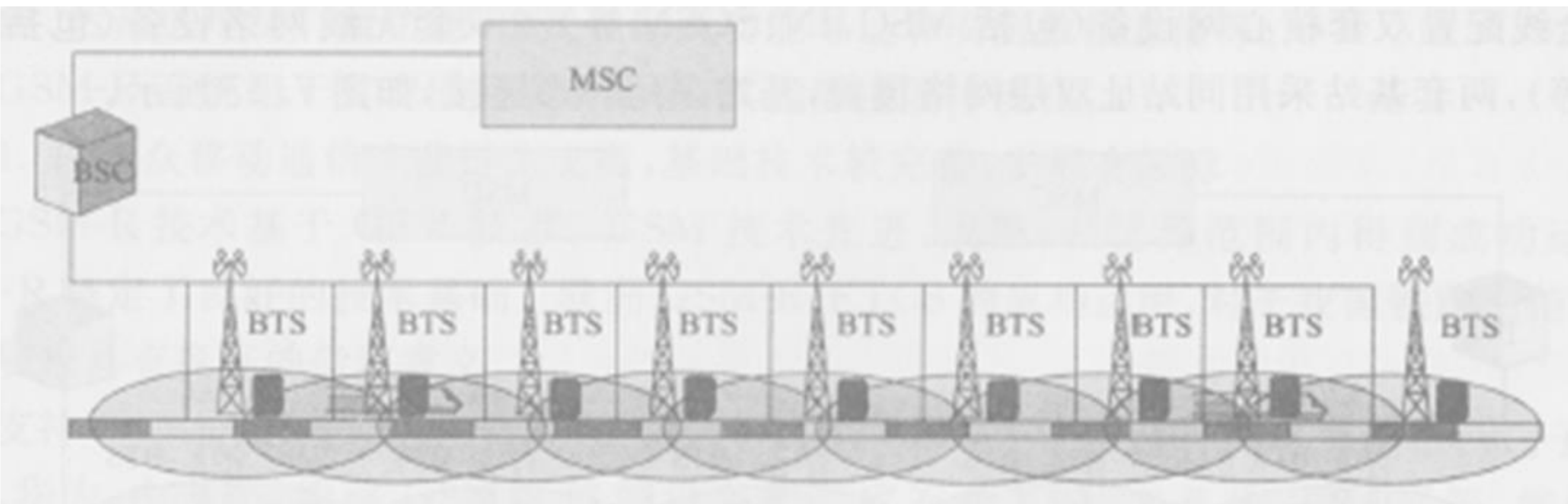
BTS
BTS



MSC
BSC
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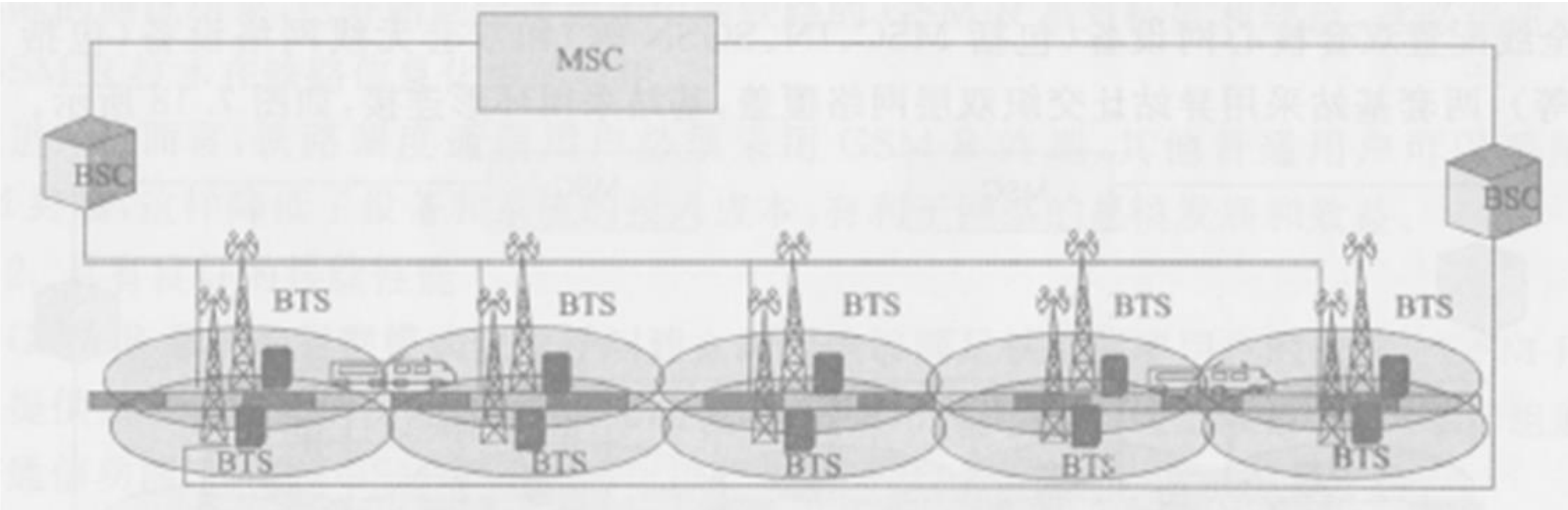
MSC
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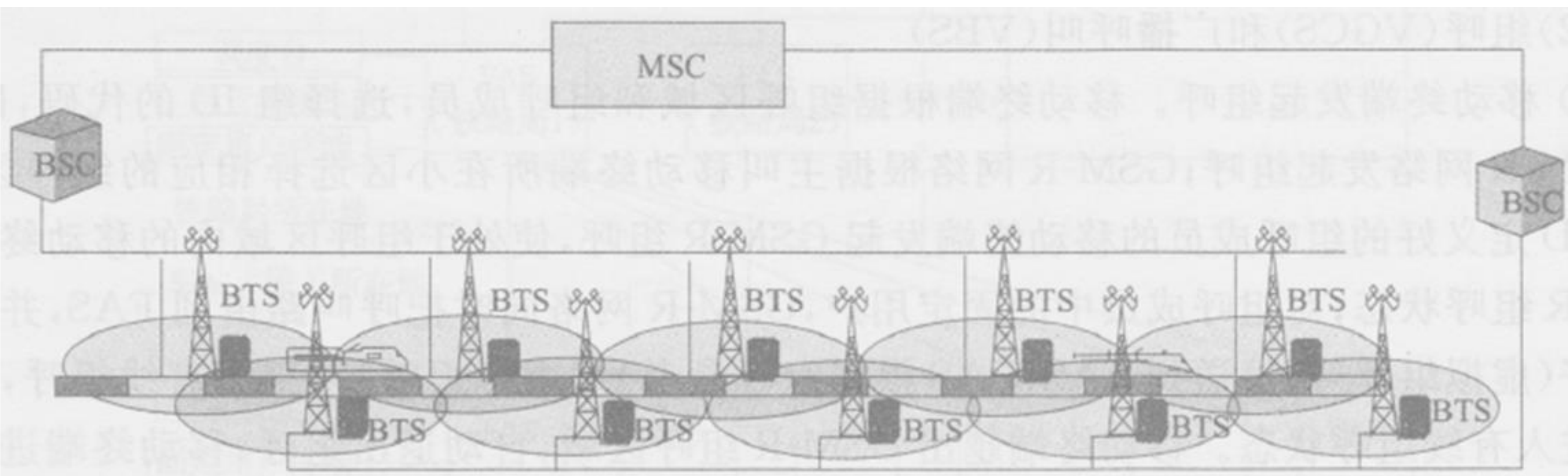
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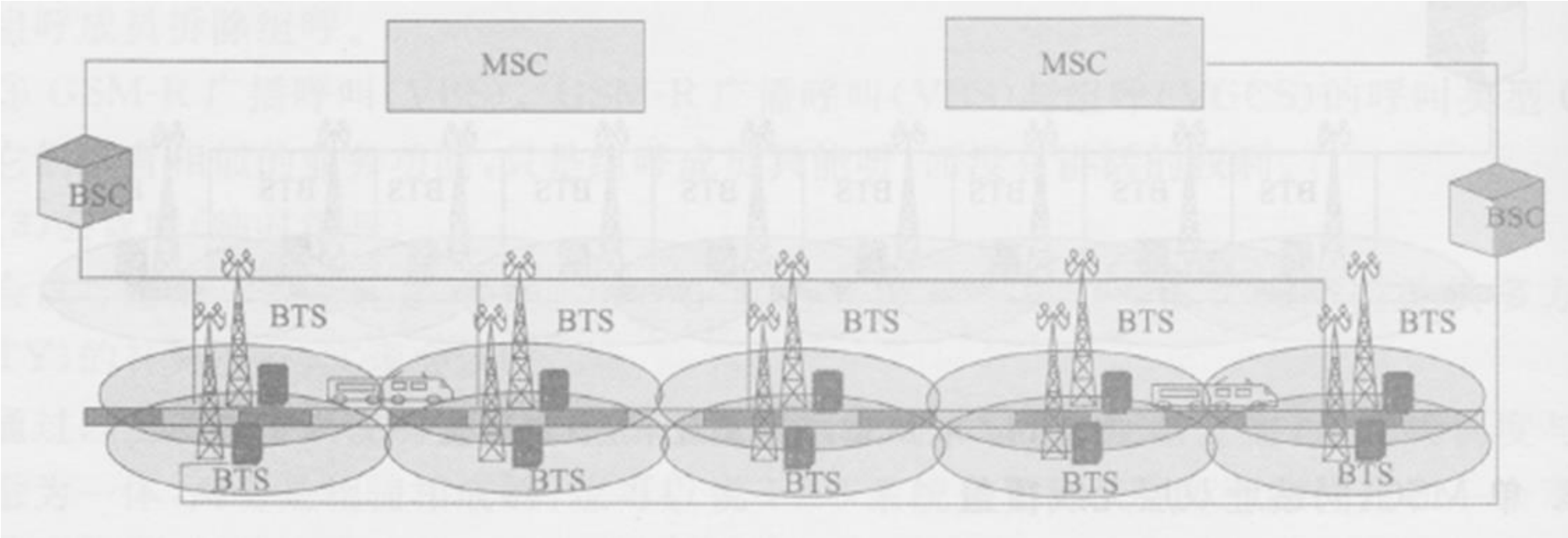
MSC
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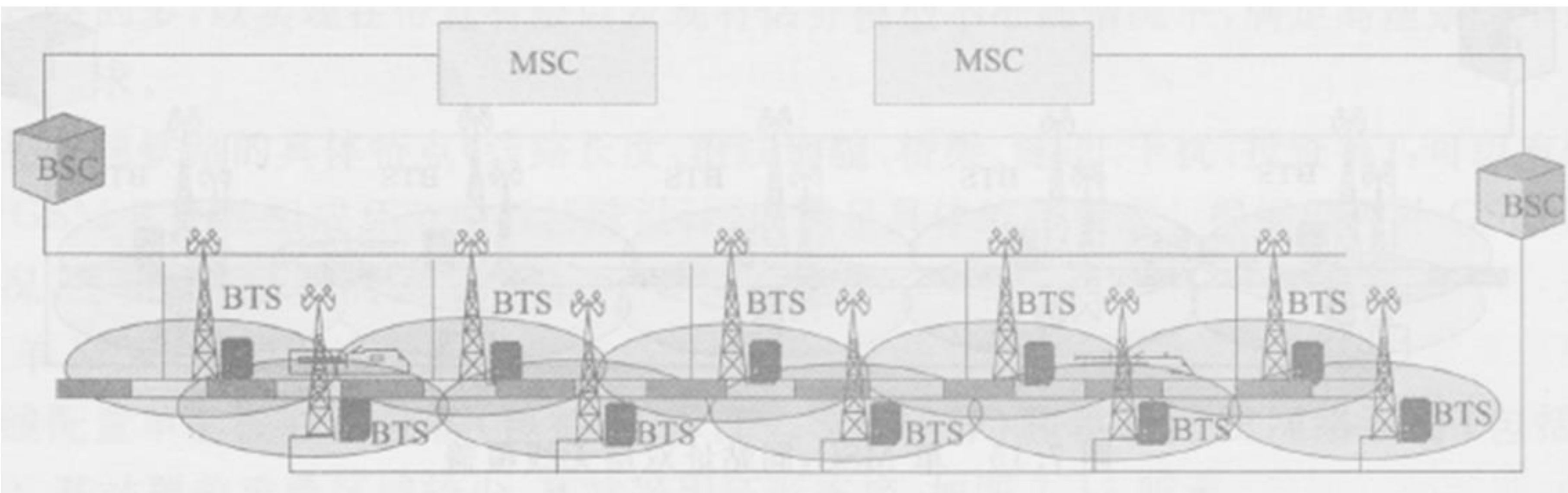
MSC
MSC
BSC
BSC
BTS
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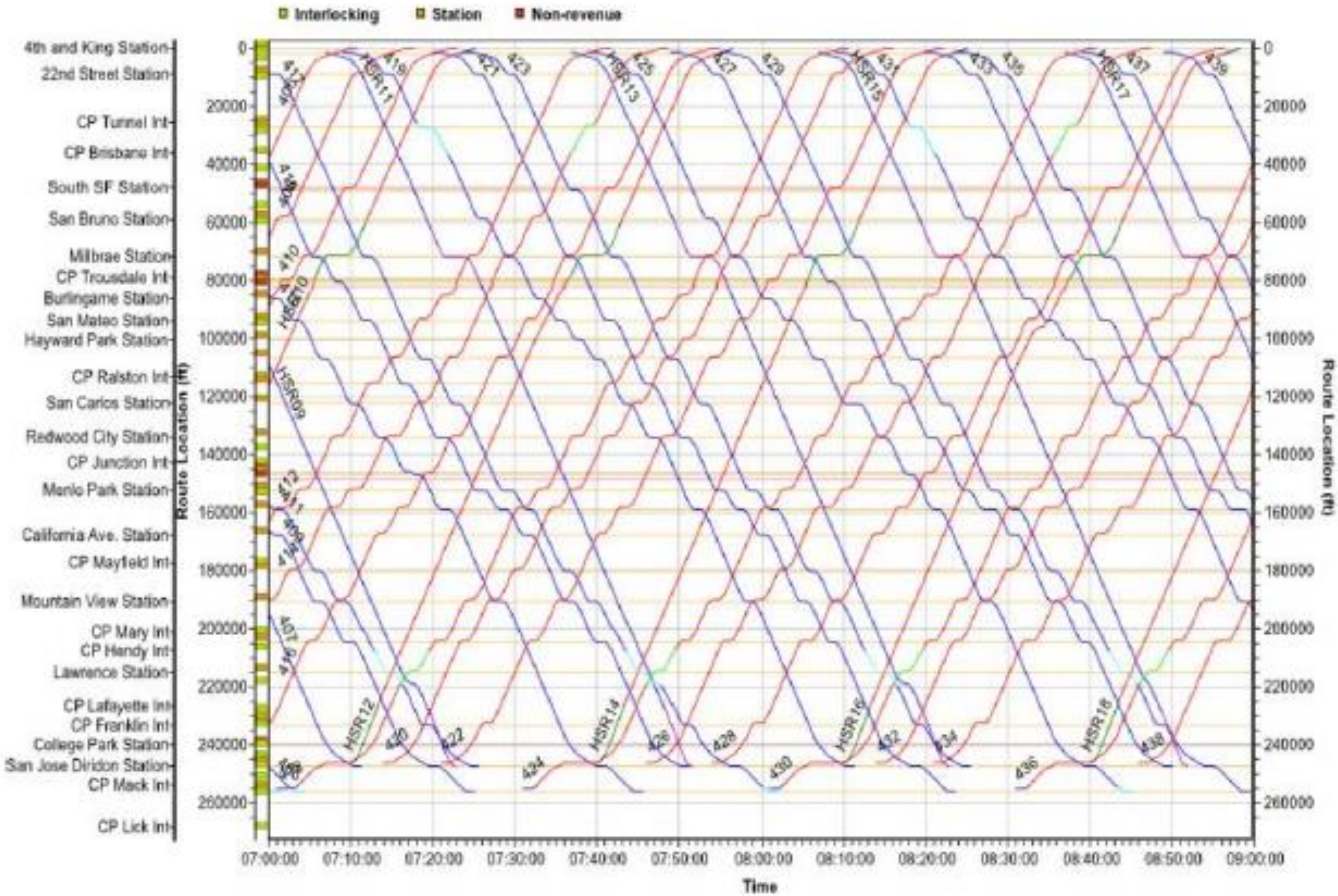
BTS
BTS

HSR Operation

Outline

- What is HSR operation?
- HSR capacity
- HSR CTC



Interlocking
Station
Non-revenue
4th and King Station
22nd Street Station
CP Tunnel Int
CP Brisbane Int
South SF Station
San Bruno Station
Millbrae Station
CP Trousdale Int
Burlingame Station
San Mateo Station
Hayward Park Station
CP Ralston Int
San Carlos Station
Redwood City Station
CP Junction Int
Menlo Park Station
California Ave. Station
CP Mayfield Int
Mountain View Station
CP Mary Int
CP Hendy Int
Lawrence Station
CP Lafayette Int
CP Franklin Int
College Park Station
San Jose Diridon Station
CP Mack Int
CP Lick Int
Route Location (ft)
Time
07:00:00
07:10:00
07:20:00
07:30:00
07:40:00
07:50:00
08:00:00
08:10:00
08:20:00
08:30:00
08:40:00
08:50:00
09:00:00
HSR11
HSR13
HSR15
HSR17
HSR09
HSR12
HSR14
HSR16
HSR18

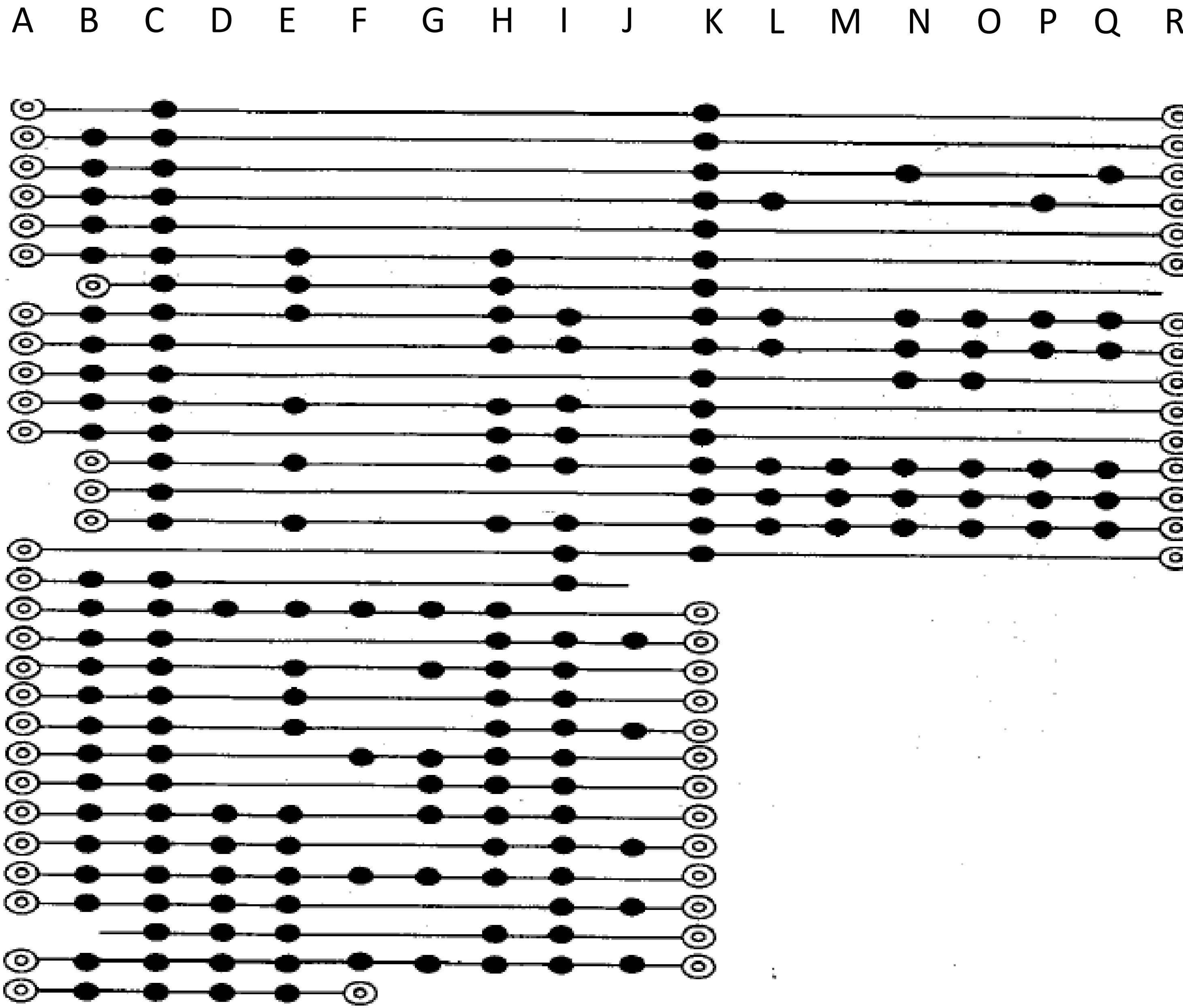
Operation plan

- Satisfy different demand
- Make transfer convenient
- Consider the use of rolling stock (number, type, maintenance, etc.)
- Consider train service crew
- Consider stop requirement
- Consider maintenance (4-6 hours, track, signal, communication, power supply maintenance at the same time)

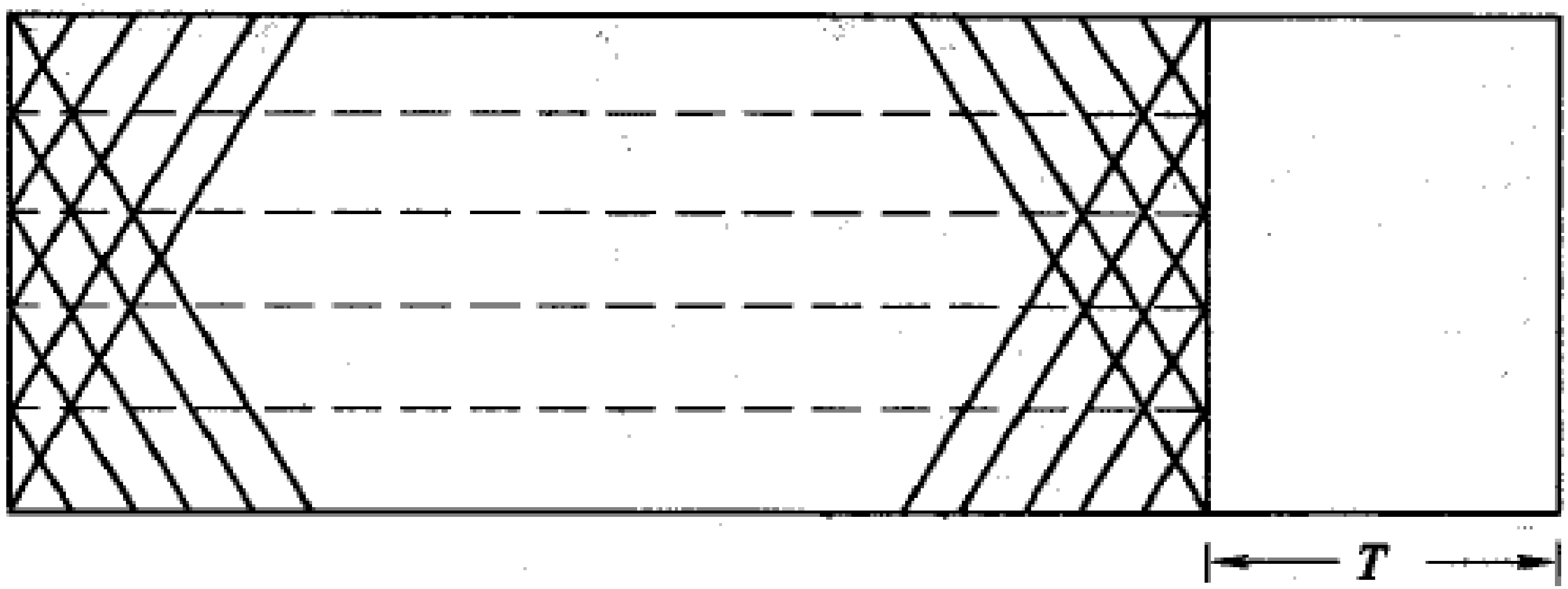
HSR passenger flow and train classification

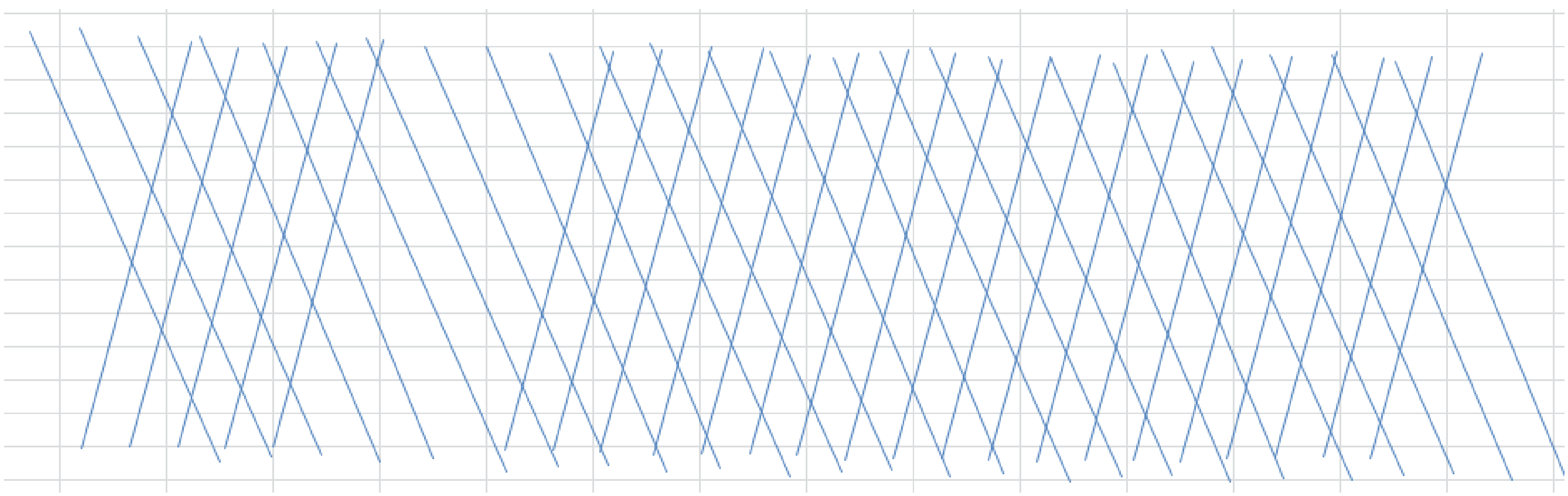
- Passenger flows
  - Different speed
  - Different travel distance
  - Different stop pattern
  - Different operating sections

	Model	Consist	KW	Max Speed	Power Distribution
Japan	200 series	14M+2T	12,880	270 km/h	power distribution
France	TGV	2M+8T	8,800	260 km/h	power concentrattion
British	APT	2M+12T	6,000	tilt train	power concentrattion
Russia	ЭР200	14M+2(C)	11,520	200 km/h	power distribution

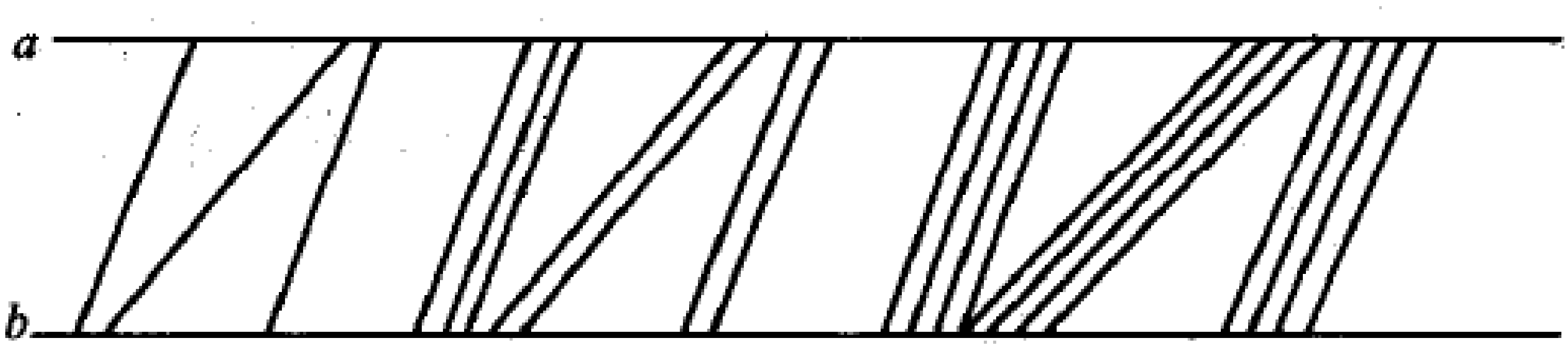

A B C D E F G H I J K L M N O P Q R

Scheduling for maintenance

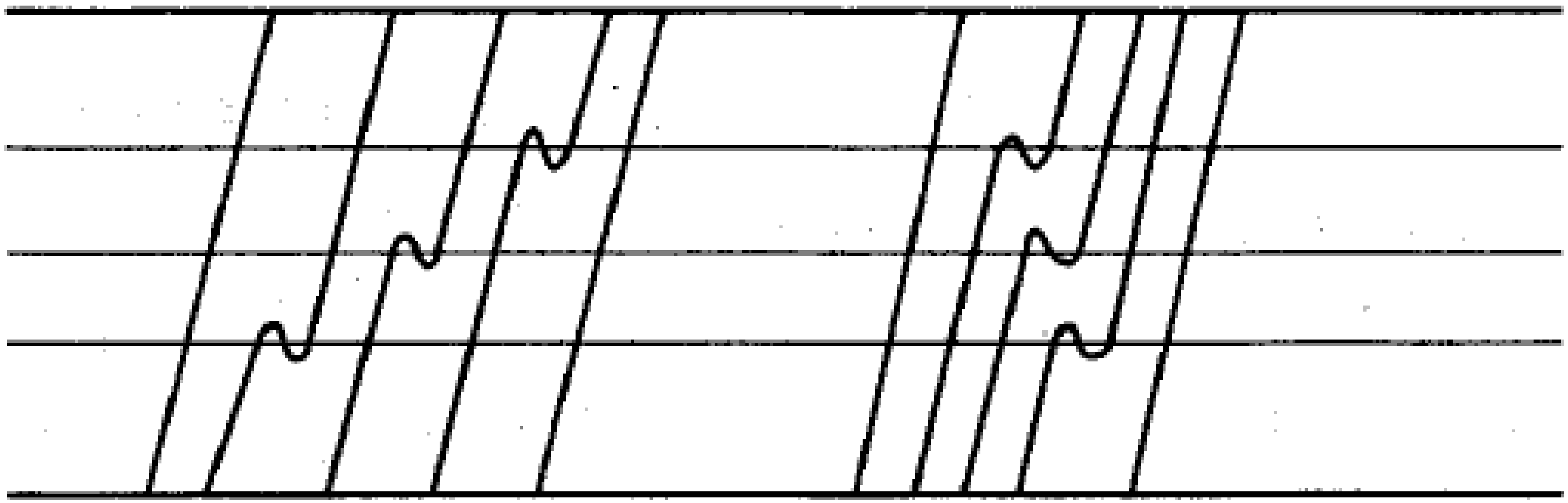


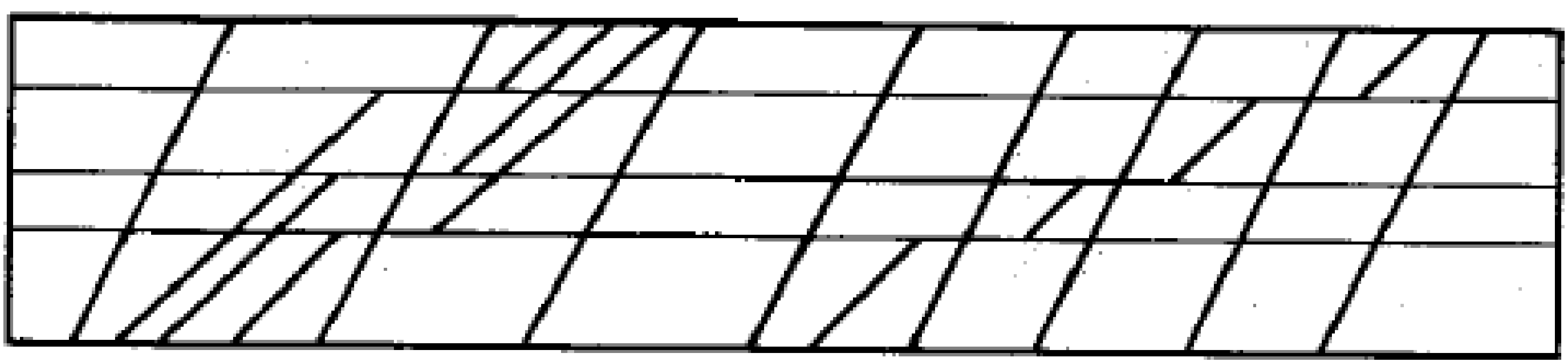


Schedule for different trains

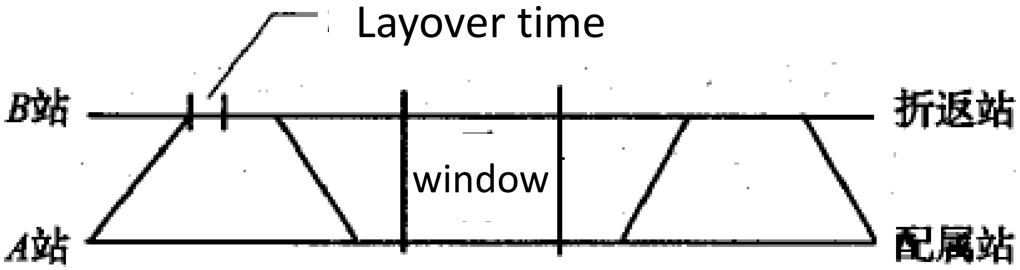


Schedule for different stop patterns

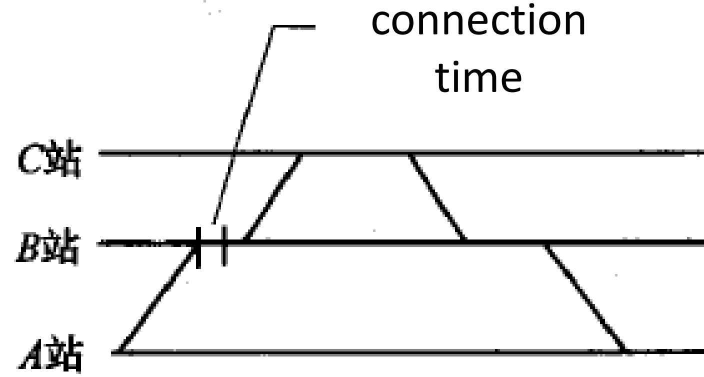




Schedule for rolling stock

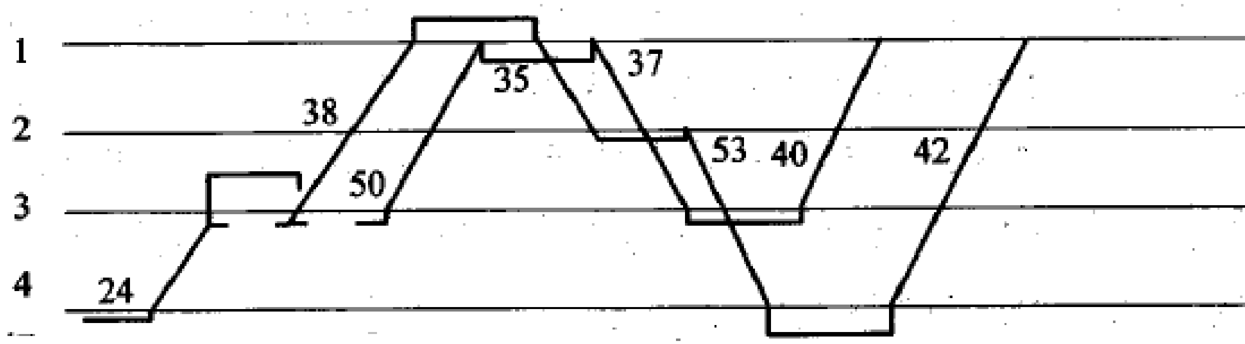


Between Station Cycle



Turn around between multiple stations

High Speed Multiple Units Fixed Service Section Service Plan



Multiple Units

High Speed Multiple Units Flexible Service Section Service Plan

HSR capacity

- Influencing factors
  - Mixed use
  - Train type, proportion
  - Following time interval
  - Speeds
  - Station dwelling time
  - Distance between stations
  - Maintenance windows
  - Scheduling method

HSR capacity (cont.)

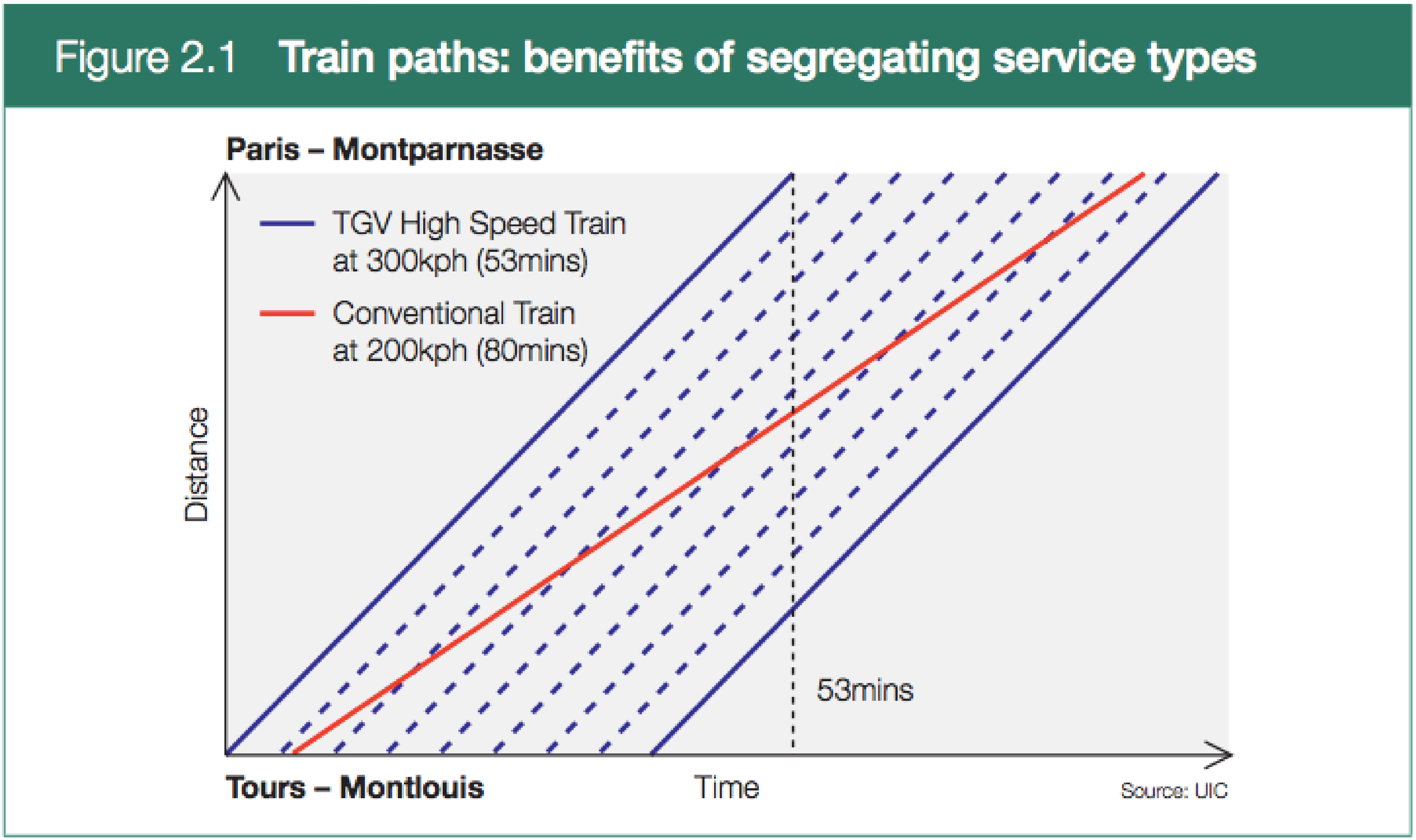
- Combination capacity: capacities for long distance trains and short distance trains
- By direction
- By section
- Day and time usage different
- Theoretical and practical capacities are significantly different
- Dwelling time and acceleration/deceleration have bigger impact

Capacity calculation method

- Influencing factor method
- Simulation

$$n_h = \frac{1440 - \left(t_{maint} + t_{misc}\right)}{I\varepsilon_h}$$

- T_{maint} – time for maintenance
- T_{misc} - time for miscellany activities
- I – time interval between trains
- ε – influencing factor



- http://www.thetransportpolitic.com/2010/07/24/the-u-s-emphasis-on-passenger-rail-and-the-future-of-freight/

Train capacity

$$C = \frac{365 C_v \alpha}{K}$$

- C= capacity for a train (passengers)
- Cv=train capacity
- α= loading factor
- K = seasonal factor

Centralized Traffic Control

- Highly planned, centralized control
- High safety
- High density
- High on-time performance
- Human centered passenger service
- Comprehensive maintenance

HST Passenger Service

HST Passenger Service

- Service
  - At station
  - On train
- Passenger information systems

Service at station

- Booking
- Loading and unloading
- Waiting
- Passenger information
- Special group of passenger service
- Extended service

Service at station (cont.)

- Booking
  - Windows at station
  - Wending machine
  - Internet
  - Telephone
  - Agents

Service at station (cont.)

- Pricing practices vary among different countries: France, Japan, Germany
- Pricing - France
  - Time varying
  - Priority consideration
    - Frequent public employee, 50% off
    - Pass for collaborating agencies like taxi
    - Point system
    - 12-25 year olds and 60+, 25-60% off
    - Veterans, etc.,

Service at station (cont.)

- Loading and unloading
  - Entering
  - Travel in station
  - Check in
  - Alight

Service at station (cont.)

- Waiting: any activities except booking and boarding and alighting
  - Shopping
  - Entertainment
  - Temporary storage

Service at station (cont.)

- Passenger information service
  - Passenger service: train status, transfer info, ticket price,
  - Announcement and travel guide: what about rail, travel guide, travel safety, service complaint, equipment usage
  - Social service: weather, hotel, hospital, fund, etc

Service at station (cont.)

- Special group of passenger service
  - Senior, child, veteran, etc.
  - VIP
  - Travel group
  - Students

Service at station (cont.)

- Extended service
  - Travel service
  - Connecting travel agencies
  - Taxi
  - Hotel booking
  - Umbrella renting

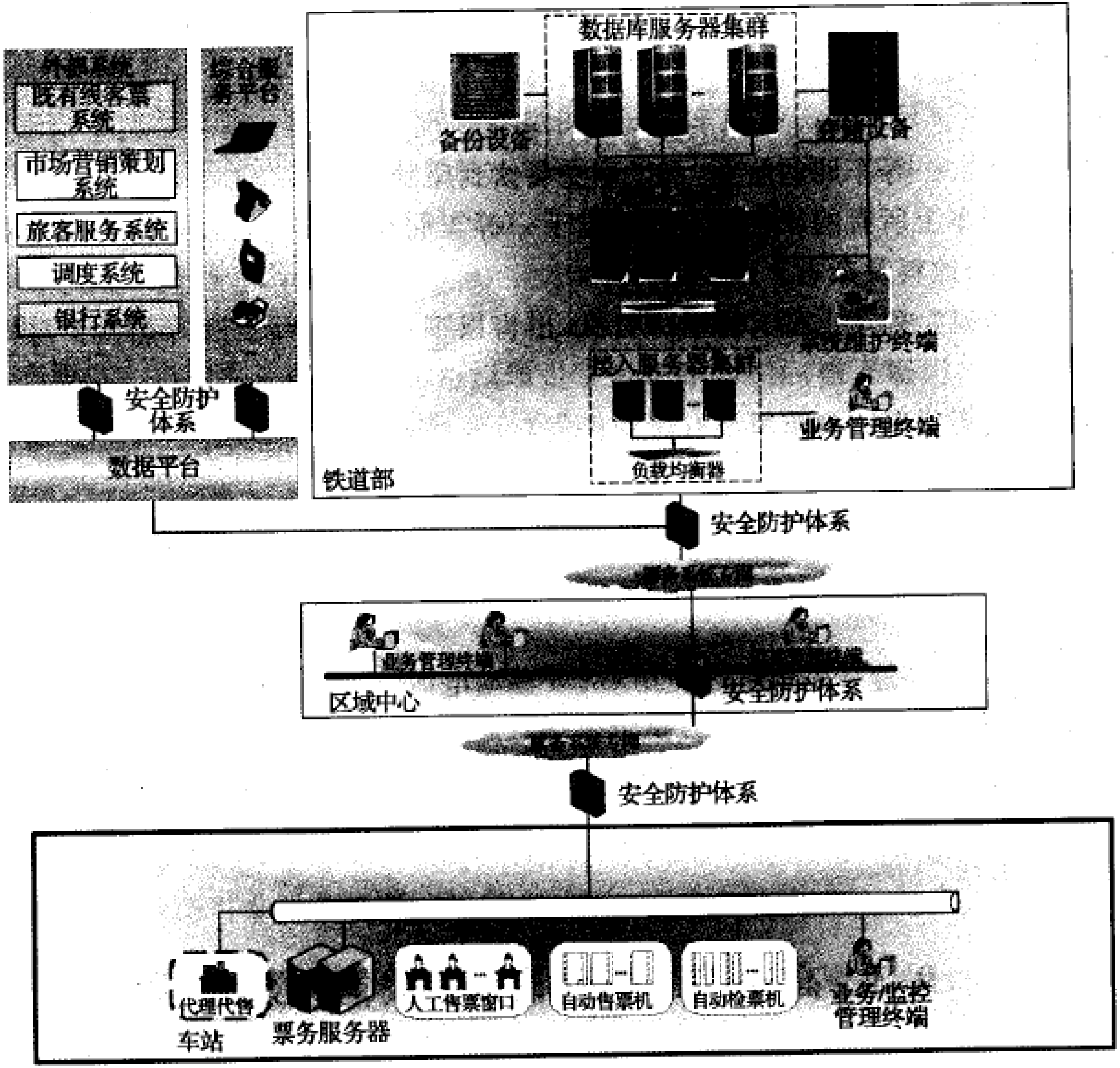
Service on trains

- Crews
- Broadcasting
- Information display
- Child care
- Service for handicapped
- Foods service
- Newspaper and magazine
- Phone on train
- Adjusted chair

Information systems

- Booking system
- Passenger service system
- Passenger marketing
- Customer service

Booking system



Booking system (cont.)

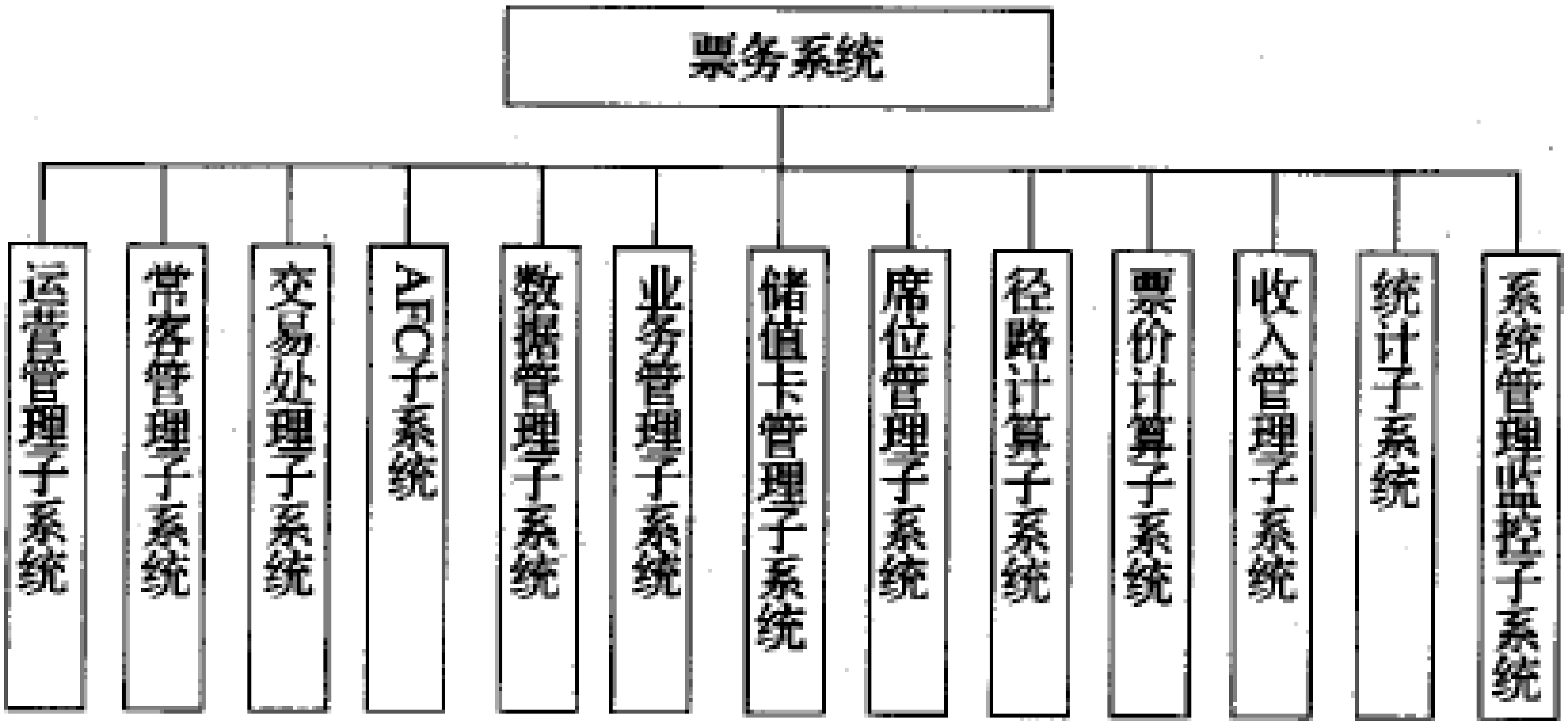


图 9.2 票务系统的功能构成

Passenger Service System

- Passenger information announcement
- Direction
- Displaying
- Monitoring
- Calling system
- Internet system

Passenger service system

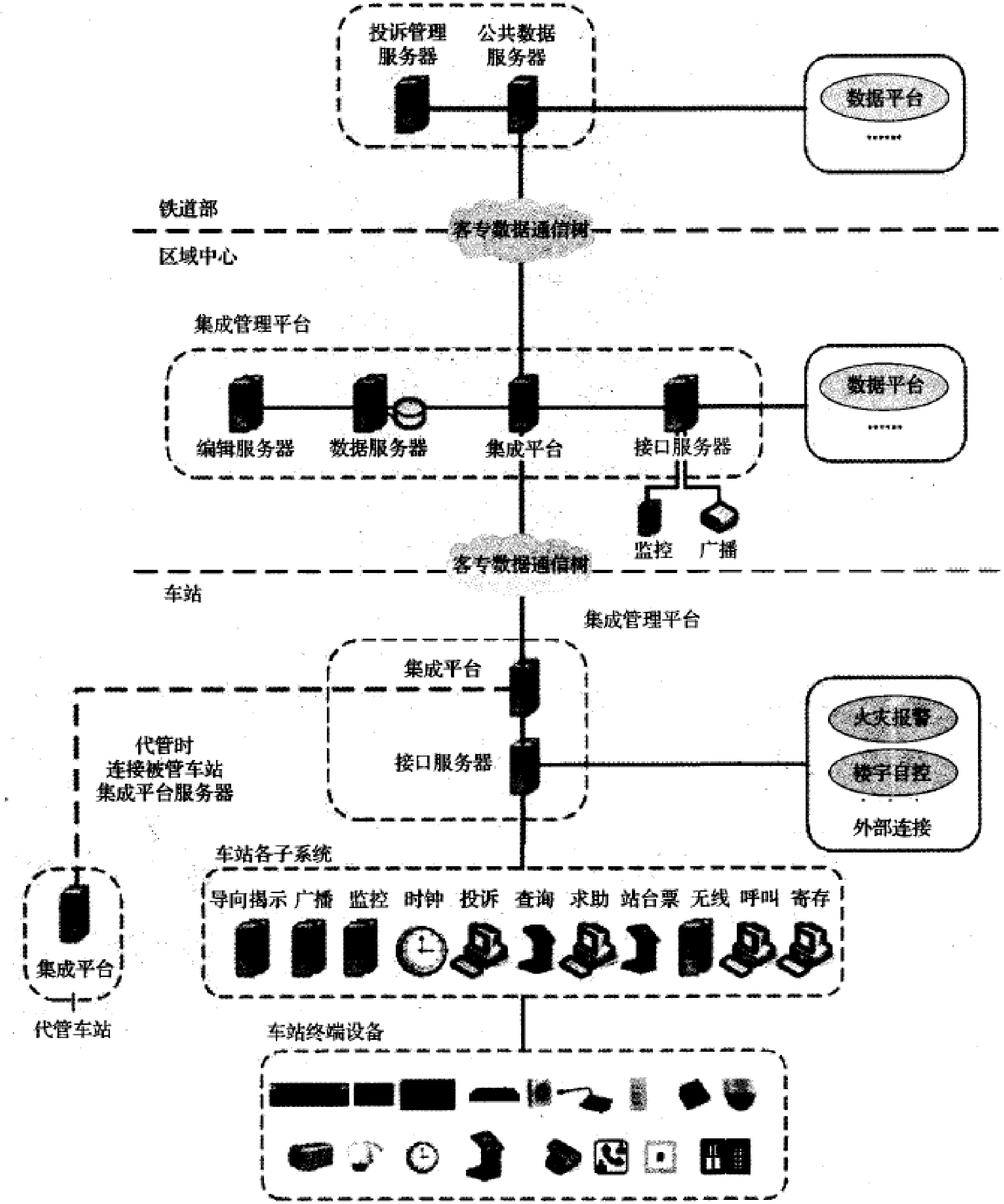


图 9.5　旅客服务系统的体系架构示意图

Passenger service system (cont.)

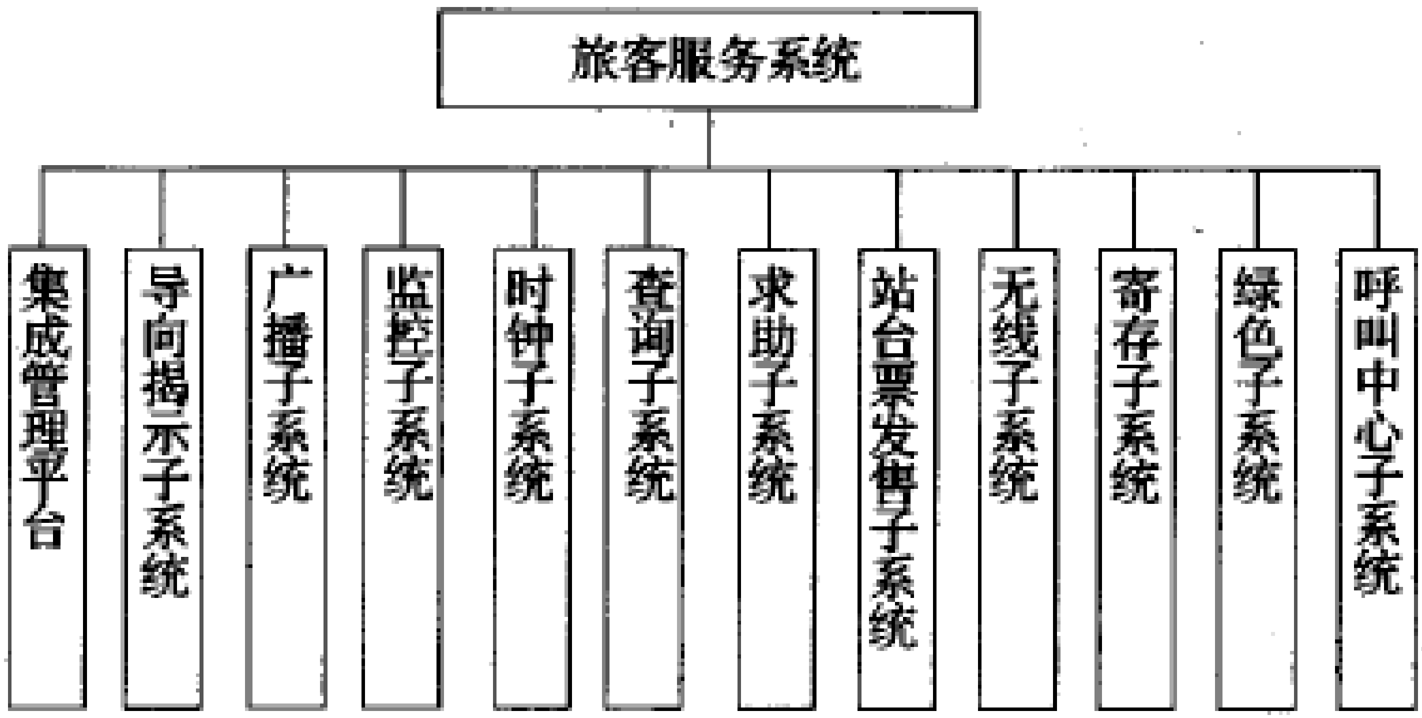


图 9.6　旅客服务系统的构成

Passenger marketing system

- Market survey, analysis and forecasting system
- Operation planning
- Analysis and assessment

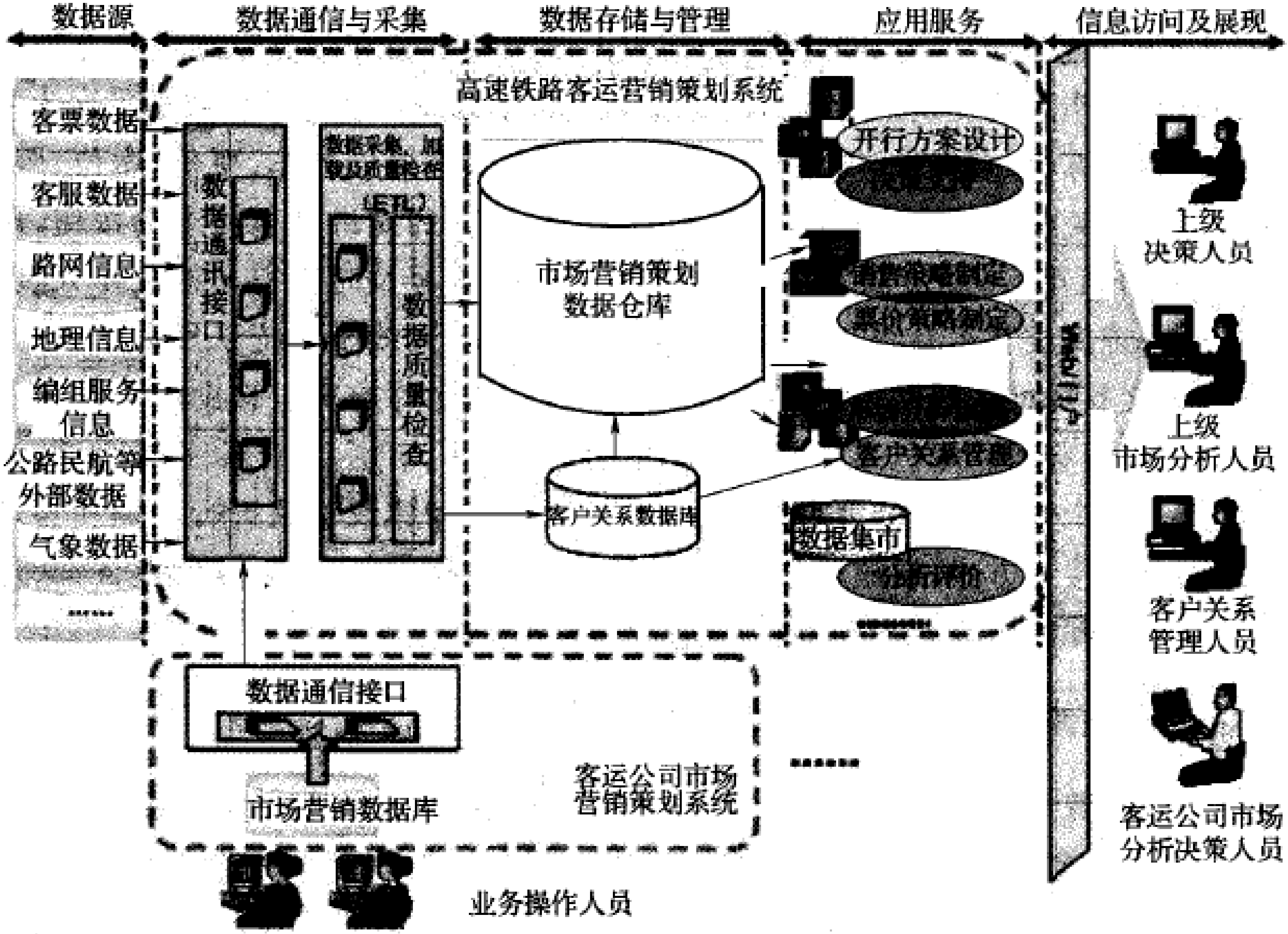


图 9.7　高速铁路客运营销策划系统结构

Passenger marketing (cont.)

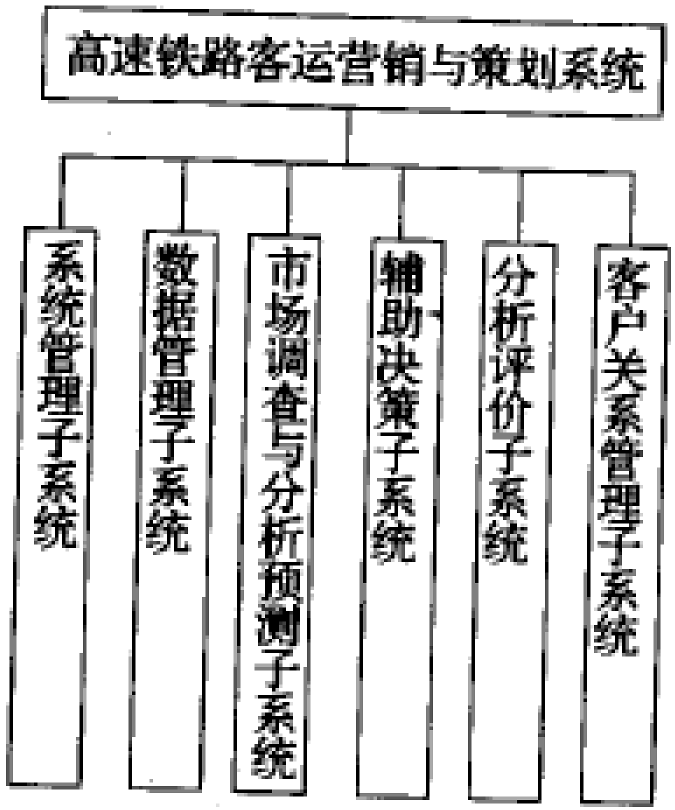


图 9.8　高速铁路客运营销策划系统构成

Customer service system

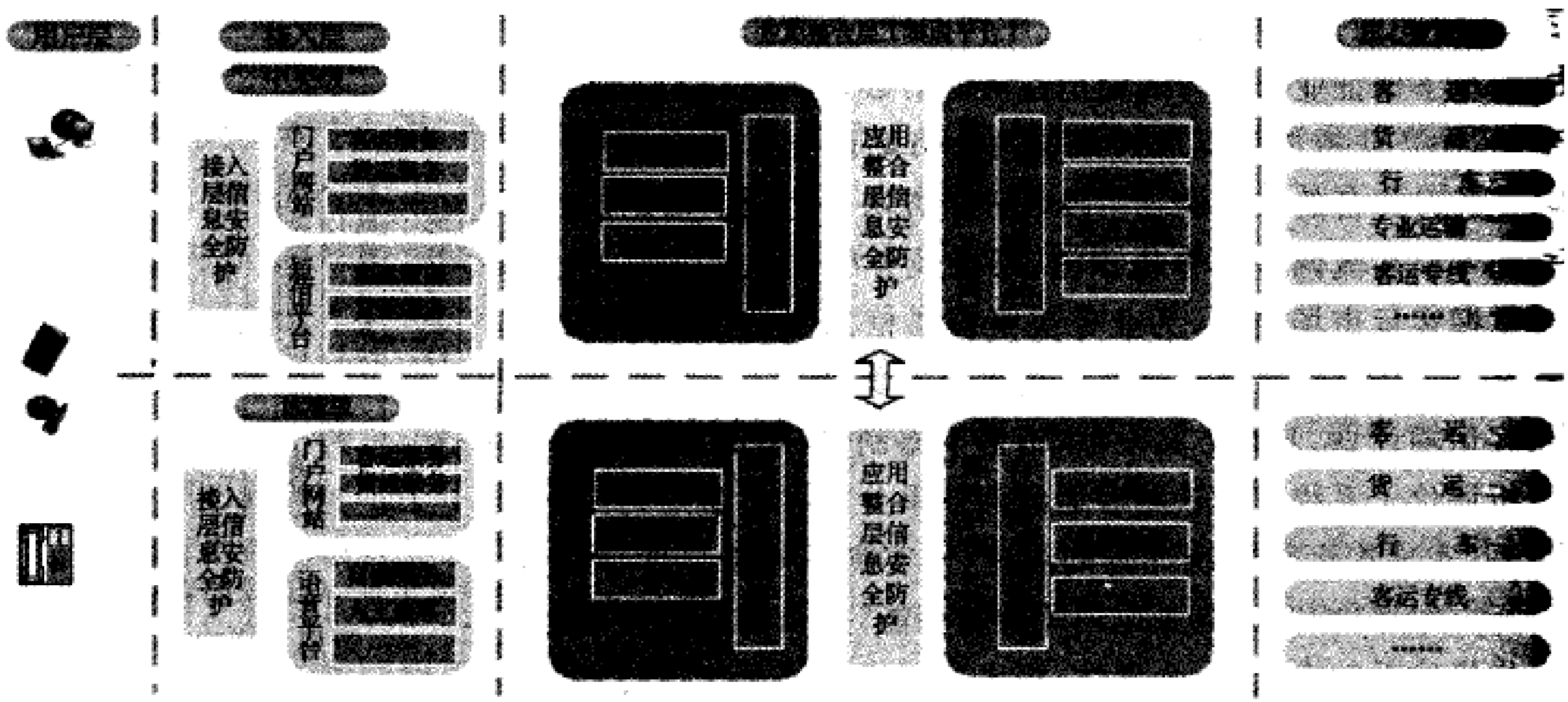


图 9.9　铁路客户服务中心系统架构

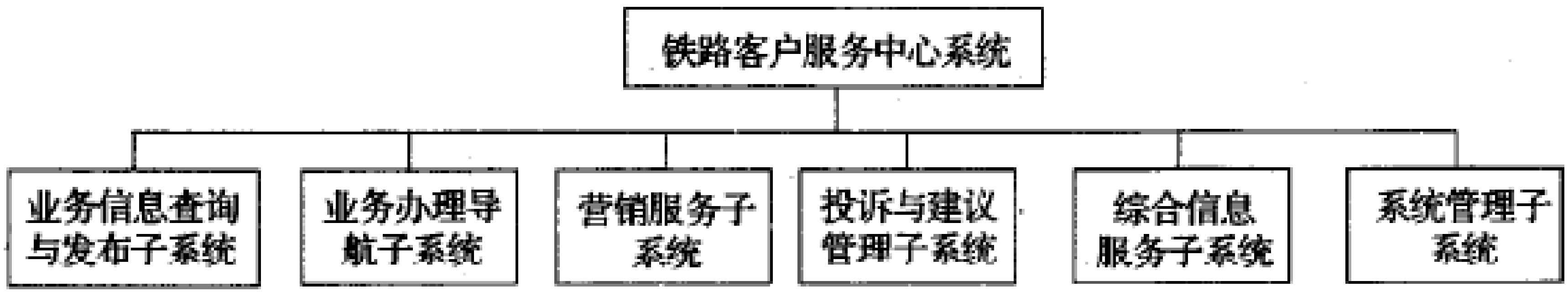


图 9.10　铁路客户服务中心功能构成图

Rolling stock and its maintenance

Onboard diagnosis

- Part diagnosis
- Vehicle diagnosis
- Train diagnosis

Vehicle part monitoring and diagnosis

- Monitor
- Monitor with input and output
- Monitor with control

Japan Shinkansen onboard monitoring and diagnosis system

表 10.1　日本新干线采用的车载监测装置

装置名称			机器监视装置	有传送功能的监视装置	有运行控制功能的监视装置
概要			做出故障记录	监视列车上的机器，连接试验操作器，根据控制作车上最少限度的检验	根据传送和接受的运行控制指令，可自动进行车上检查
功能	记录故障	故障记录	○	○	○
		追踪功能	○	○	○
	显示	故　障	—	○（发生故障，车辆项目、控制）	○（发生故障，车辆项目、控制）
		装置开放状态	—	○	○
		出库检查	—	○（出库前有无异常）	○（出库前有无异常）
		制　动	—	○（指令级、制动缸压力）	○（指令级、制动缸压力）
		牵引状态	—	○（指令级位、主回路电压电流）	○（指令级位、主回路电压电流）
		车门信息	—	○（门的关闭状态、几号车）	○（门的关闭状态、几号车）
		累计电力	—	○	○
		故障记录	—	○（有无故障记录、内容）	○（有无故障记录、内容）
	收集试运行数据		—	○	○
	车上试验		—	○（主控制器为手动操作）	○（除检查主控制器本身外，不操作主控制器，用显示器指令自动进行）
	控制运行指令		—	—	○
	补充控制指令		—	○	○

Maintenance idea and policy

- Maintenance idea
  - Preventive based, wear and tear theory based
  - Reliability based, reliability is time invarying
- Maintenance policy
  - Preventive
  - Status based
  - Emergency based, suit to system with many redundancy
- High speed rail use status based and preventive maintenance

HSR maintenance facilities

- Vehicle preparation
- Vehicle testing
- Wheel surface inspection
- Axle inspection
- Wheel and bogie replacement
- Vehicle cleaning and wash inside and outside

HSR maintenance characteristics

- Integration of operation, preparation, and maintenance

Japan Shinkansen

- Preventive, scheduled maintenance
- Consider the type of equipment and the operation schedule (6 am – 12 pm)
- Four level
  - Daily inspection and maintenance: pantagraph, brake, bogie
  - Weekly inspection and maintenance: under vehicle body check, ATC
  - Annual (450,000 km) inspection and maintenance: bogie, separate the train
  - 3 years (900,000 km) inspection and maintenance:

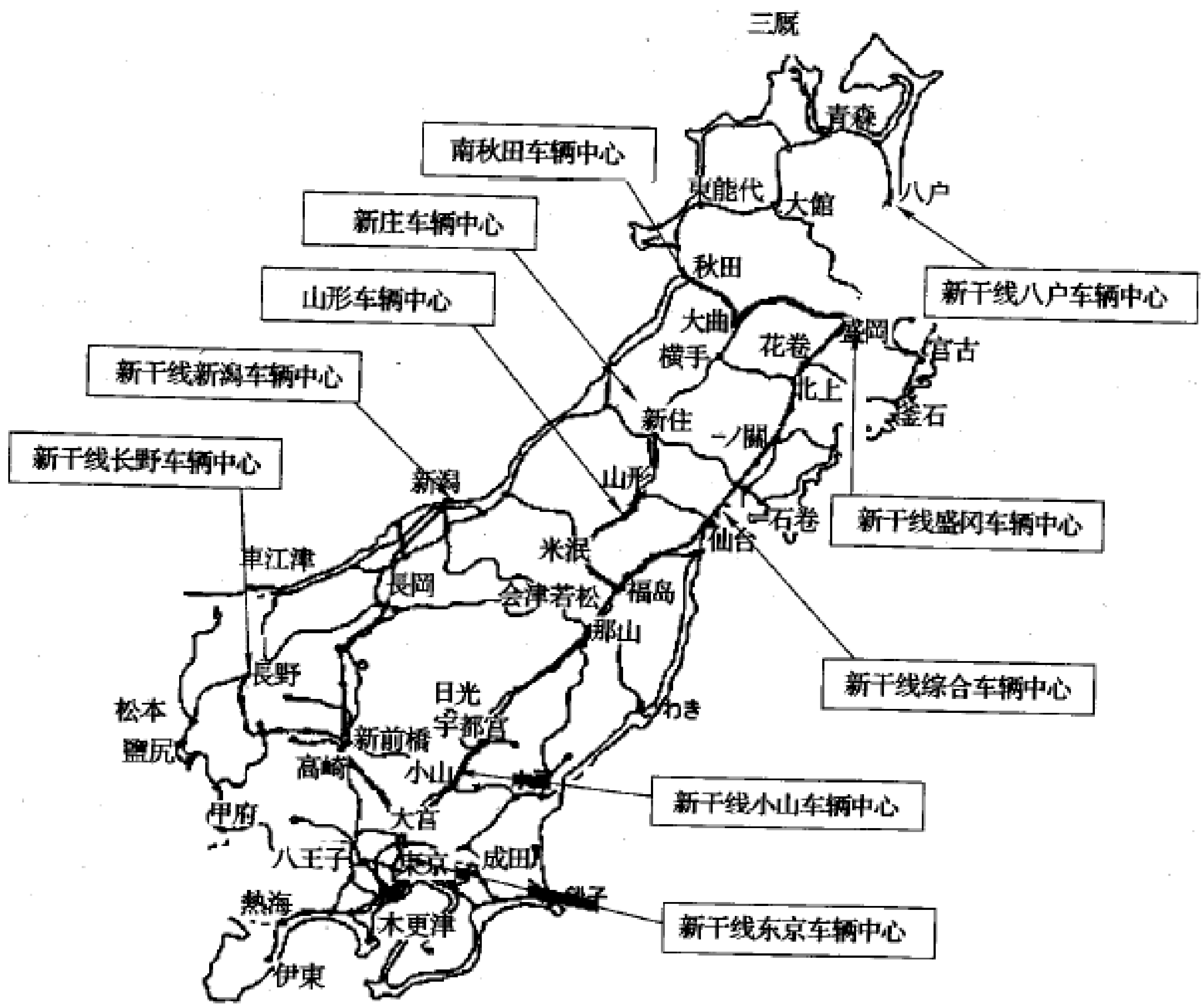


图 10.4　JR 东日本公司的新干线车辆基地

HSR Maintenance in Germany

- Scheduled and status based maintenance combined
- A,B,C maintenance level
- Maintenance facilities are distributed considering maintenance level
- Reliability based

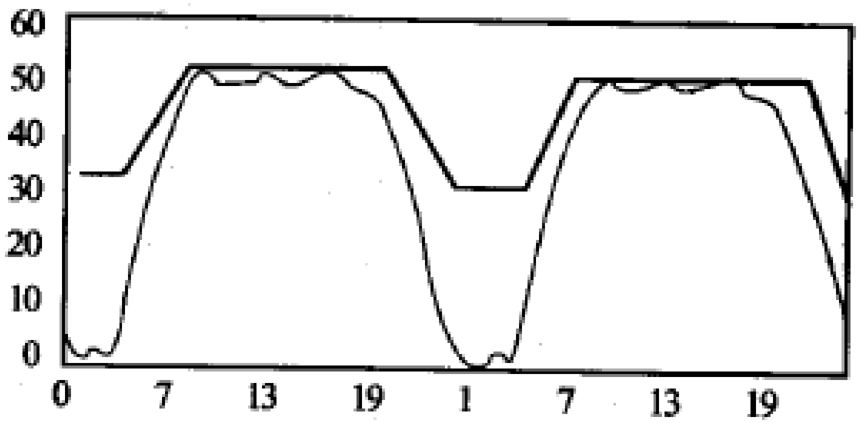
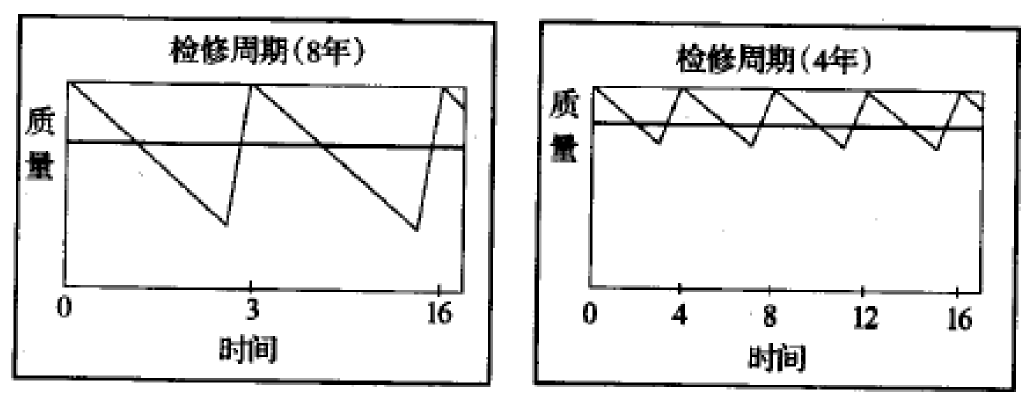


图 10.5 列车运行的高峰低谷情况安排维修计划



(a) (b)

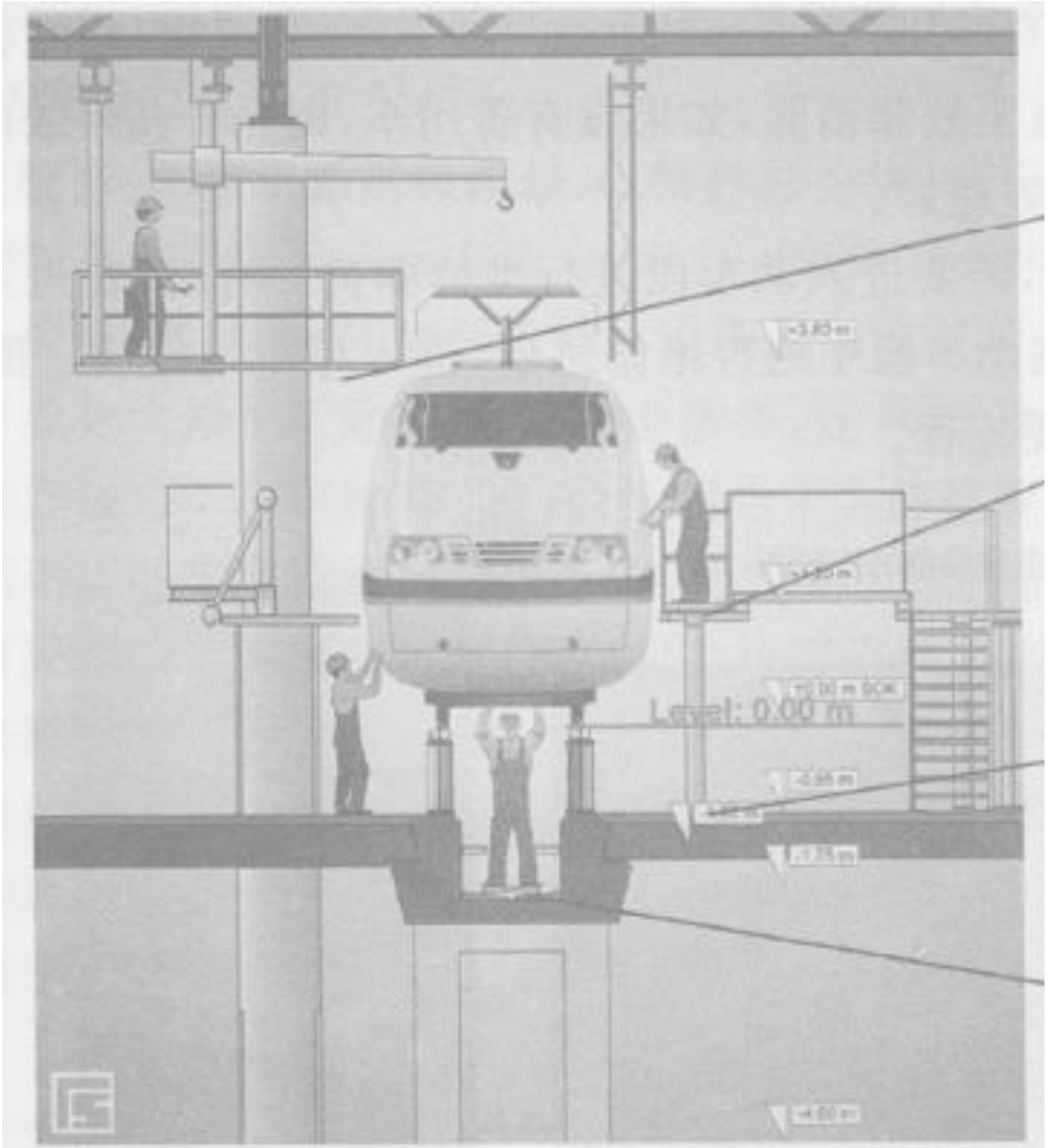
图 10.6 质量与检修周期的关系

表 10.3　动车组修理等级

等级	项　　目	走行里程(km)	检修时间	等级	项　　目	走行里程(km)	检修时间
A	L 级检修(IS100)	2 000～4 100	1.5 h	B	IS530 级检修	240 000～288 000	11 h
A	N 级检修(IS200)	20 000～24 000	2.5 h	B	IS540 级检修	480 000～576 000	11 h
B	IS510 级检修	60 000～72 000	9 h	C	IS600 级大修	120 万～140 万[illegible]	[illegible]d
B	IS520 级检修	120 000～144 000	9 h	C	IS700 级大修	240 万～[illegible]	[illegible]

- A: inspect, maintenance
- B: replace parts
- C: maintain entire trains

图 10.7　ICE 动车段到主要设备的连接图


Level: 0.00 m

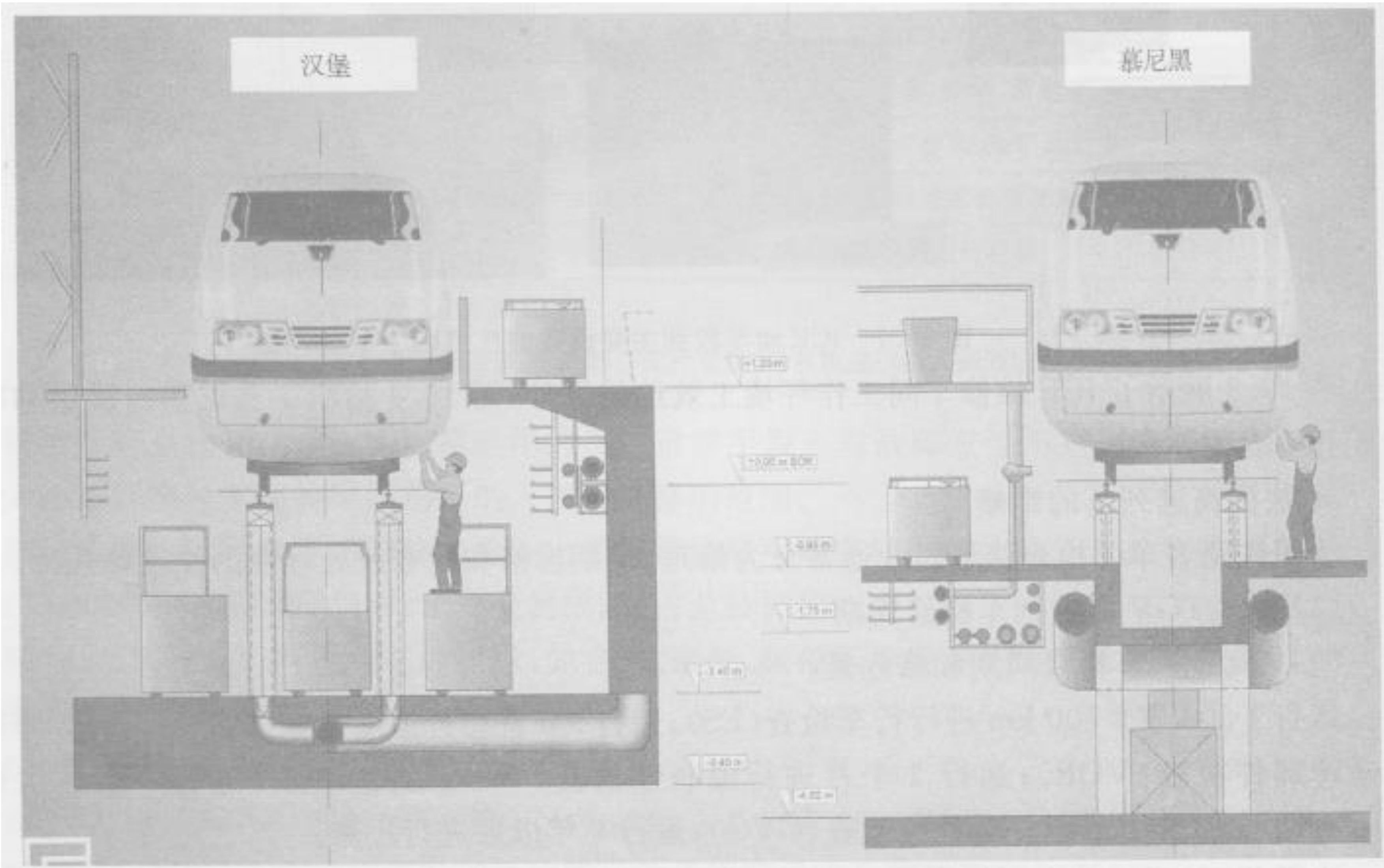


图 10.9　慕尼黑与汉堡动车段工作平台的比较

Track safety inspection and maintenance

Comprehensive inspection train

Comprehensive inspection train (cont.)

- Complete data collection: clearance, track, steel and wheel, pantograph, signal, telecommunication, environment monitoring
- Geographical location information
- The same size of train as the train in service

Track inspection technologies

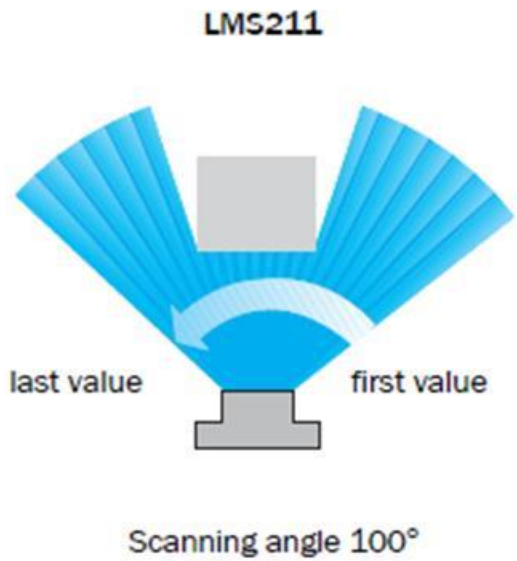
1. Track limit and cross section inspection
2. Rail wear and tear
   - Gauge
   - Vertical smoothness
   - Longitudinal smoothness
   - Level
   - Triangle dent
   - Vibration acceleration
   - Track structure and parameters
3. Wheel and rail interaction
4. Pantograph inspection
5. Communications inspection
6. Signal inspection
7. Comprehensive analysis

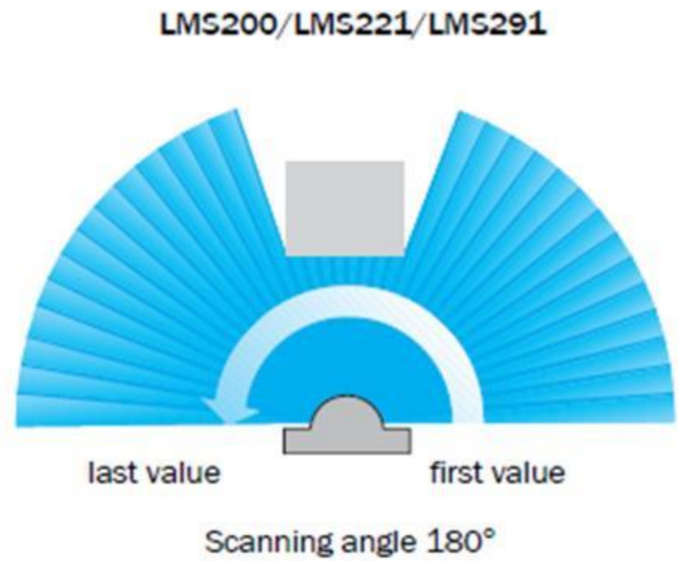
https://en.wikipedia.org/wiki/Loading_gauge

http://model-railroad-hobbyist.com/node/9160

LMS200/221/221/291 Laser Measurement Systems

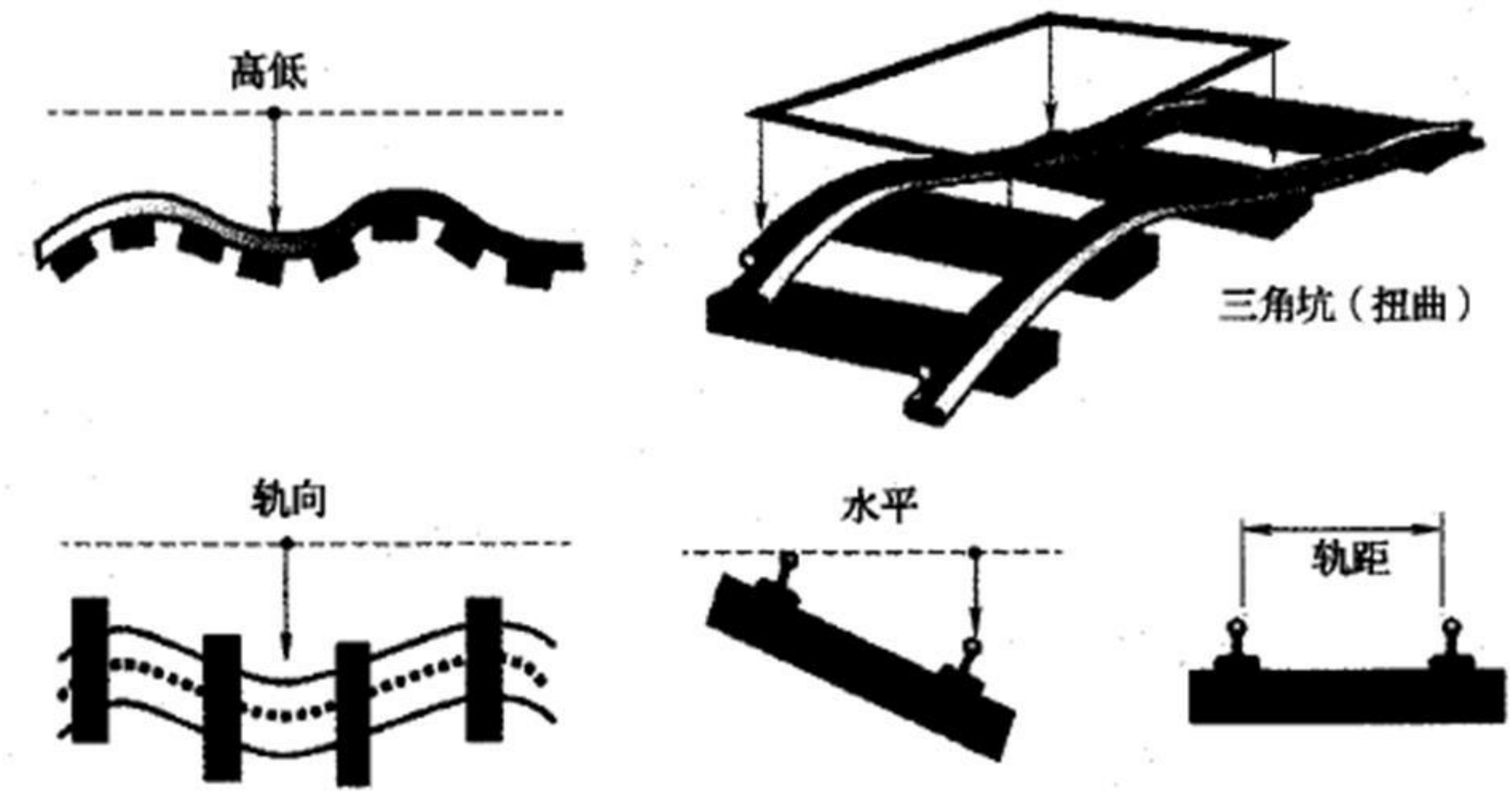
LMS200

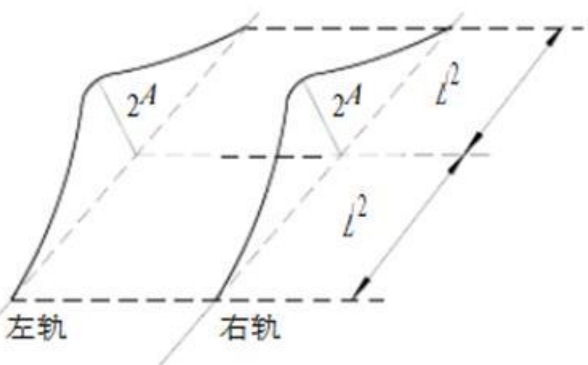




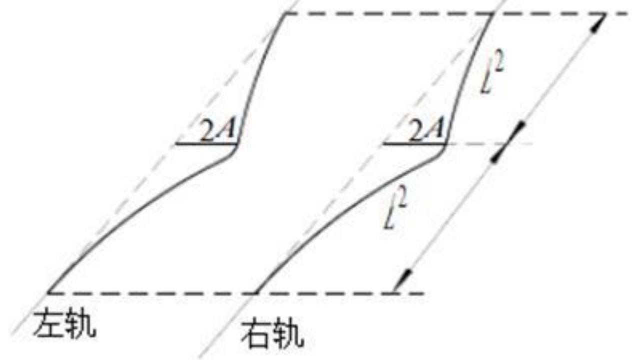
- sicktoolbox.sourceforge.net/docs/sick-lms-technical-description.pdf

Track irregularities

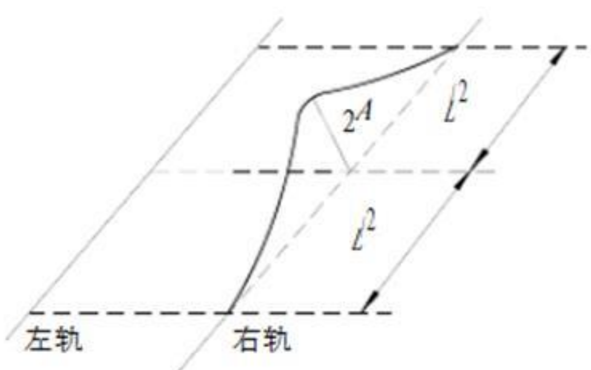




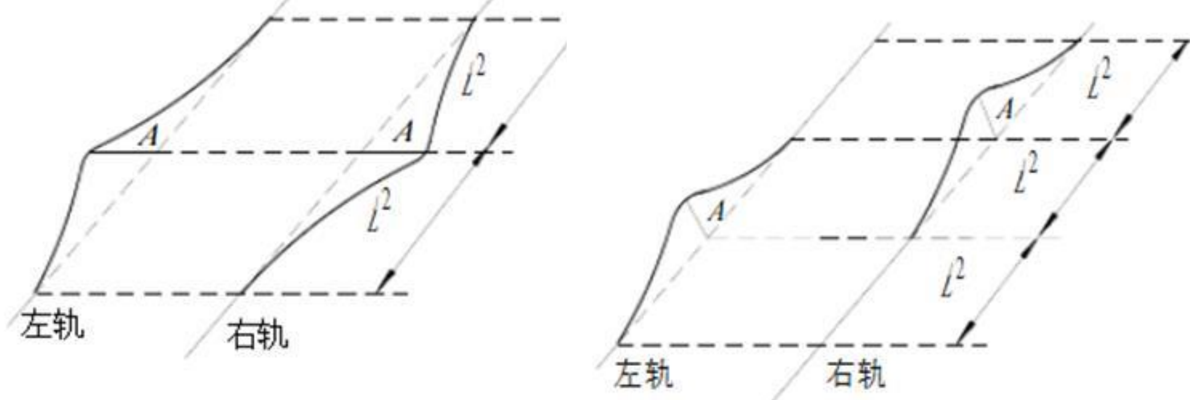
（a） 高低不平顺



（b） 轨向不平顺



（c） 水平不平顺



（d） 轨距不平顺

Rail wear and tear

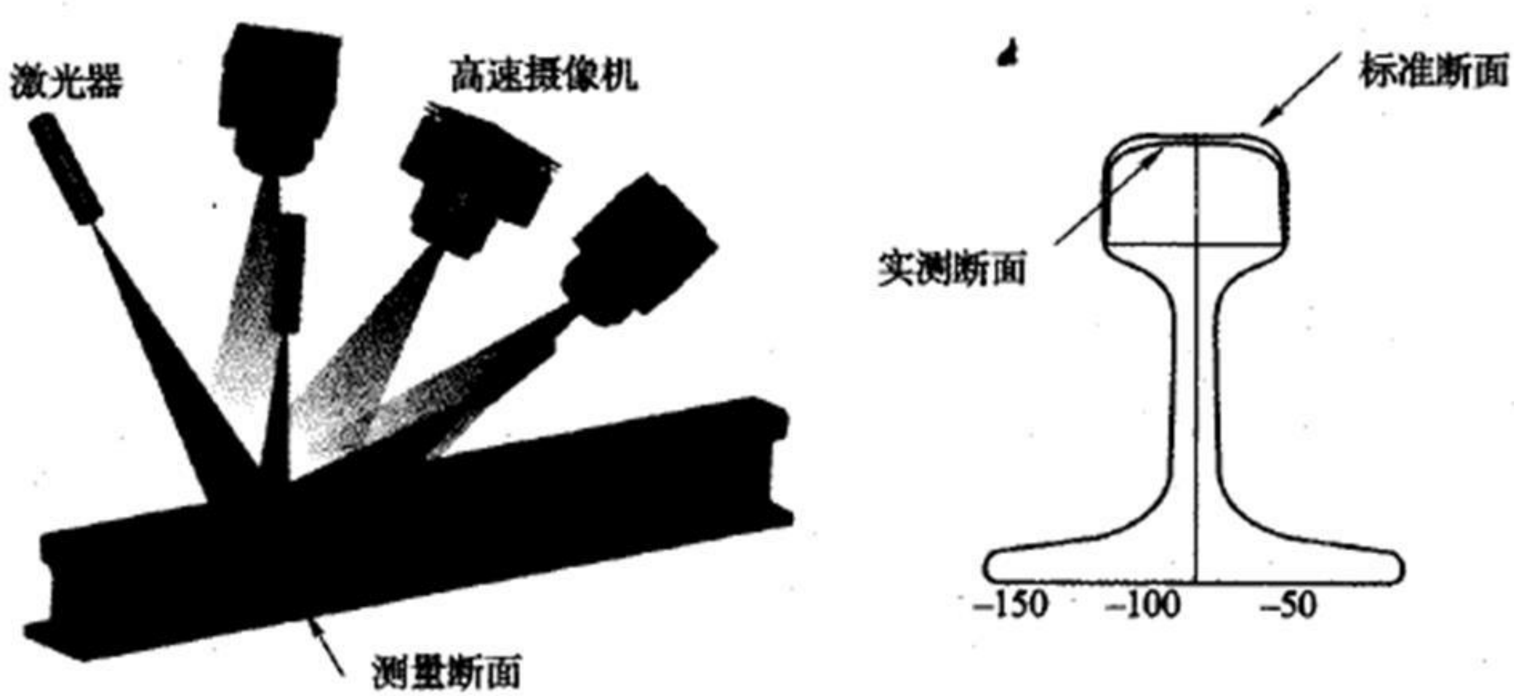
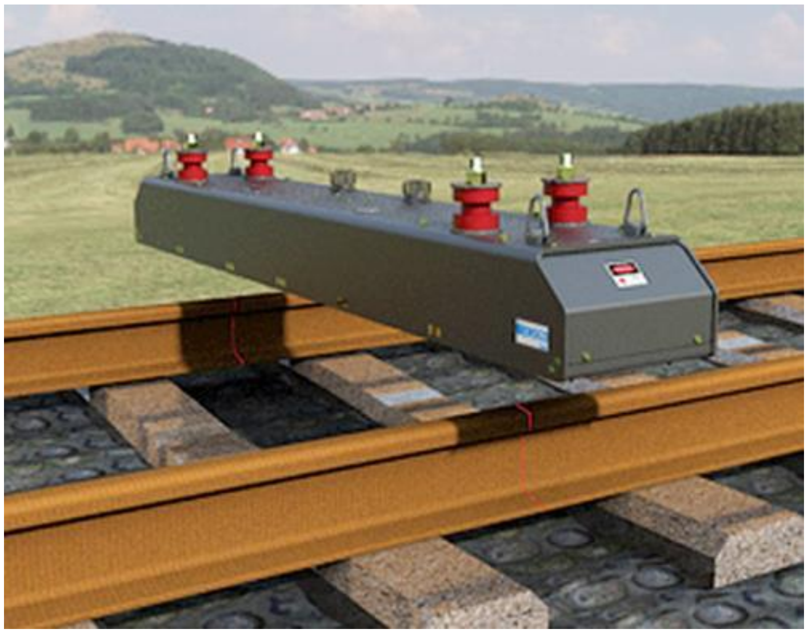


图 10.18　钢轨断面的三角形摄影测量

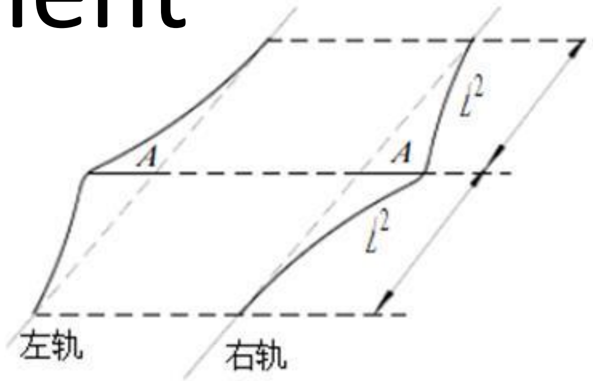
- One shot per 20-10 cm

Track Measurement Systems - ENSCO Inc.



- http://ensco.com/rail/track-measurement-systems

Gauge measurement



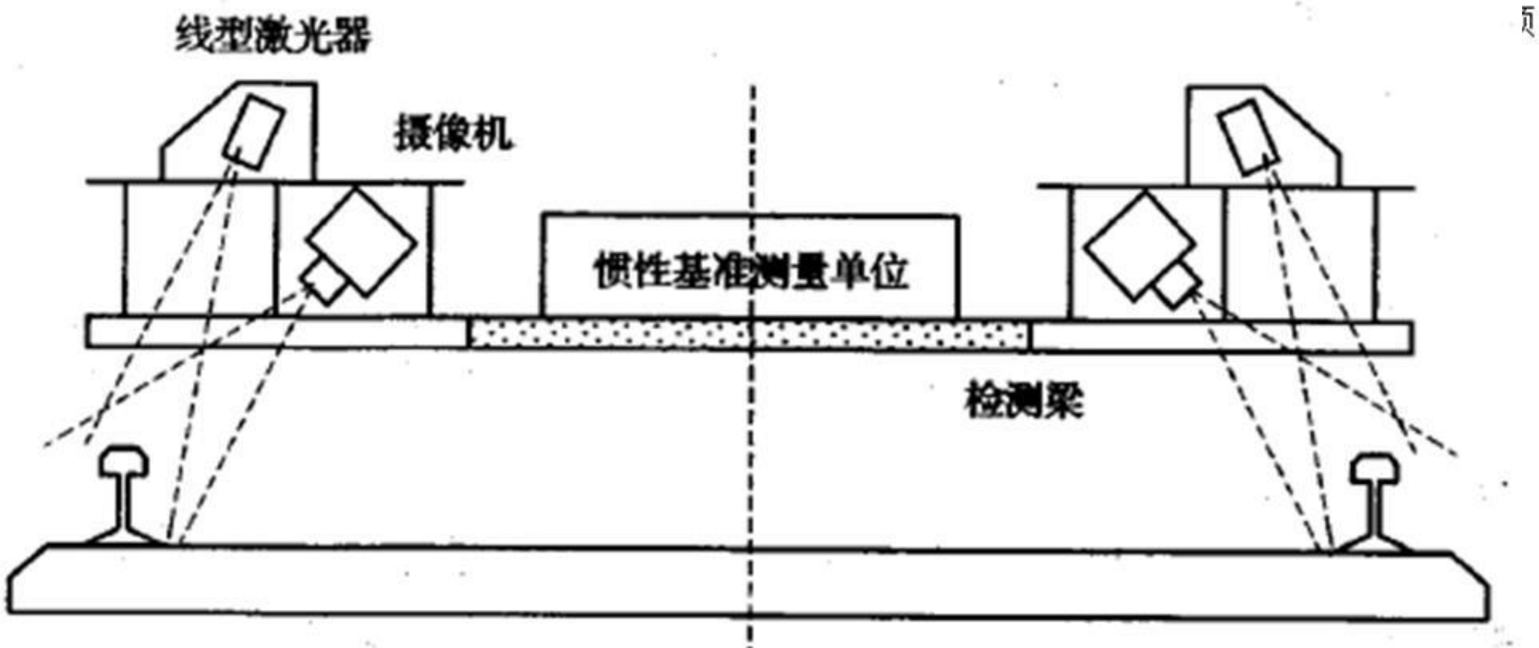
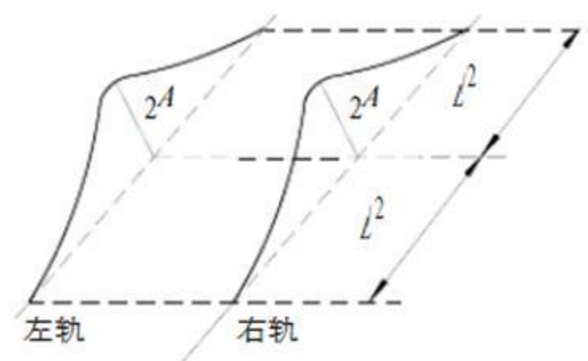


图 10.19　摄影测量式轨距测量原理

Profile irregularity - Measuring method

- Chord measuring method
- Inertia surveying system



（a） 高低不平顺

Profile irregularity (cont.)

- Chord measuring method
  - Not influenced by speed

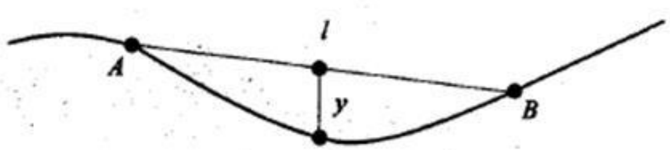


图 10.20　三点等弦弦测法

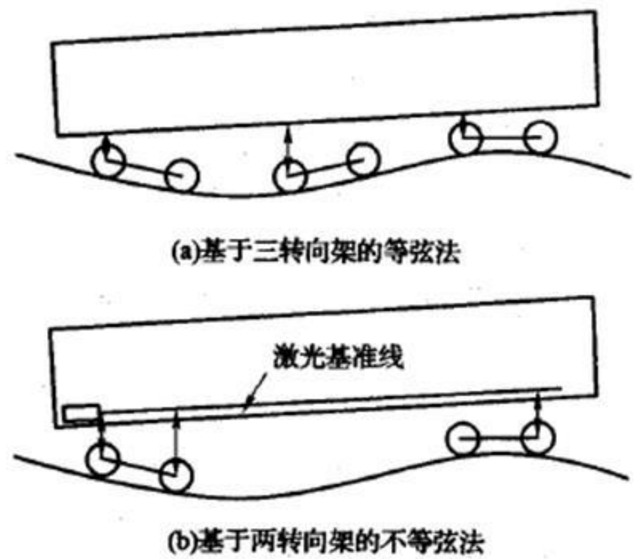


图 10.21　基于弦测法的高低不平顺动态测量

Profile irregularity (cont.)

- Inertia surveying system
  - Not good for low speed

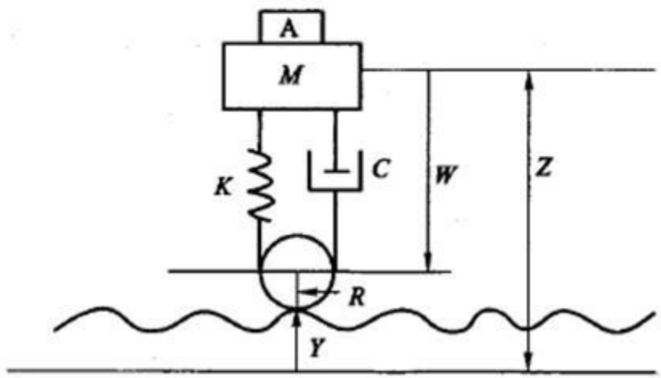


图 10.22 惯性基准法测量原理图

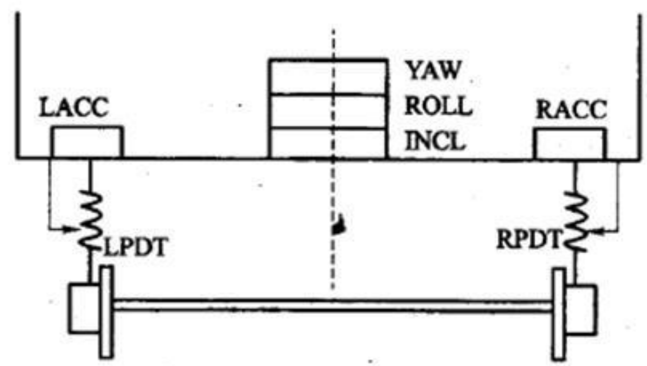


图 10.23 惯性基准测量系统

Profile irregularity (cont.)

- Good for both speeds

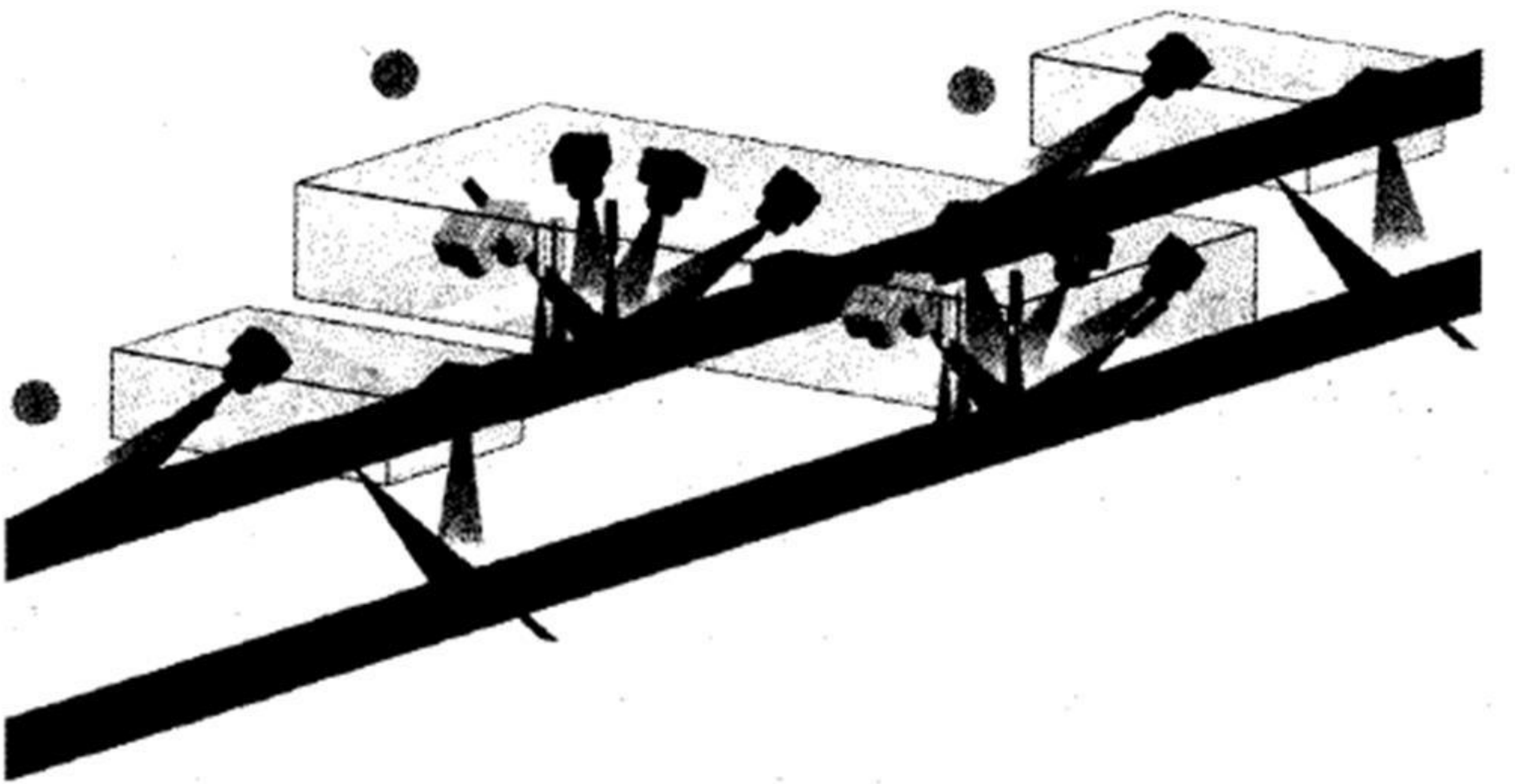
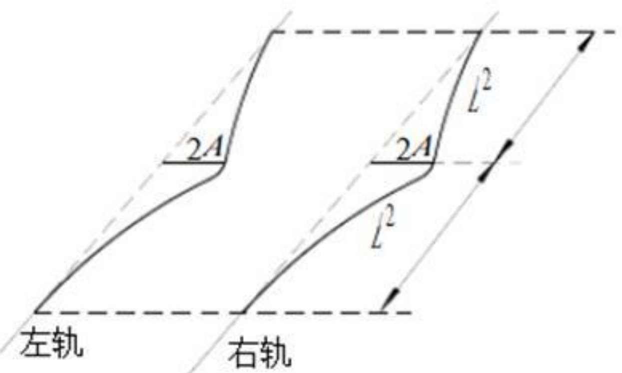


图 10.24 基于惯性技术和三点弦测法的阿基米德号轨道几何集成检测系统

Track orientation

- Combine gauge and inertia surveying system



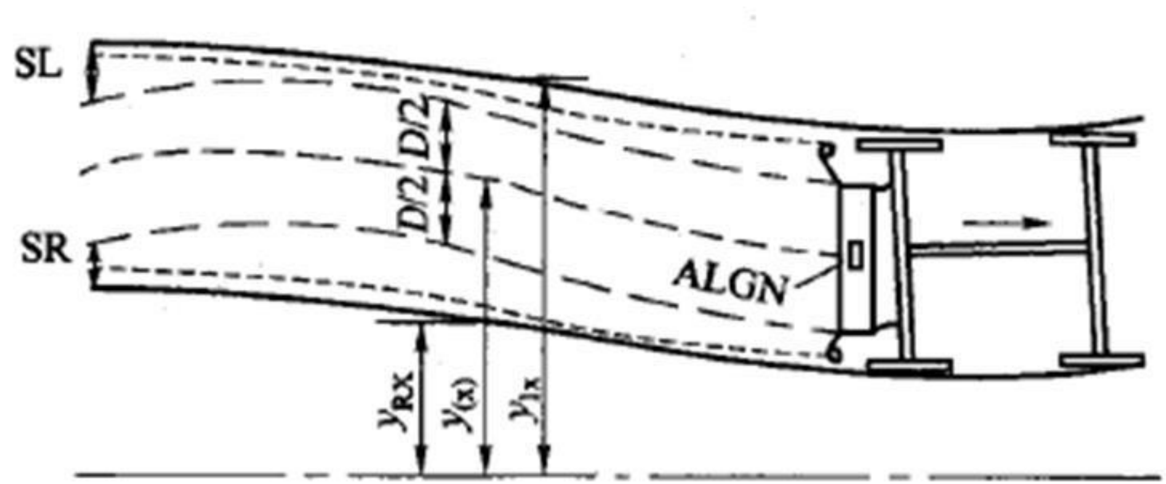
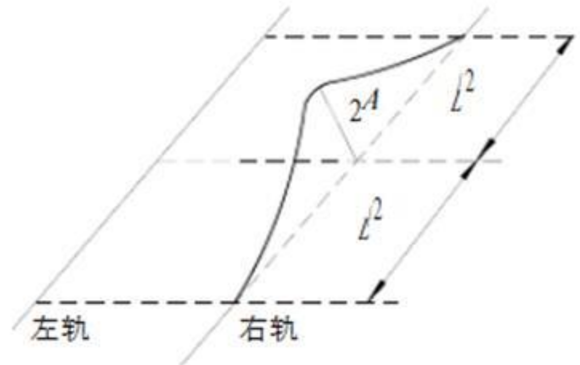


图 10.25 轨向不平顺检测示意图

Cross level irregularity



（c） 水平不平顺

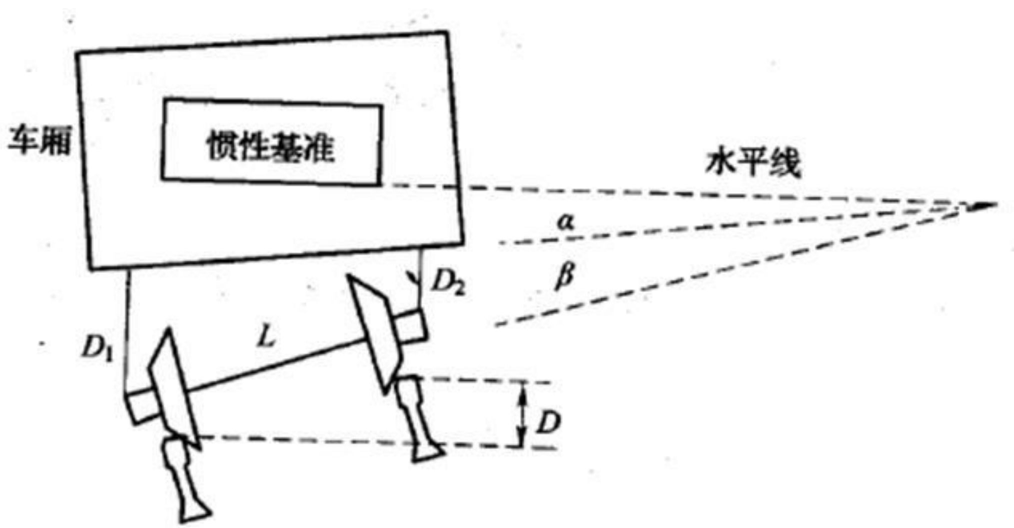
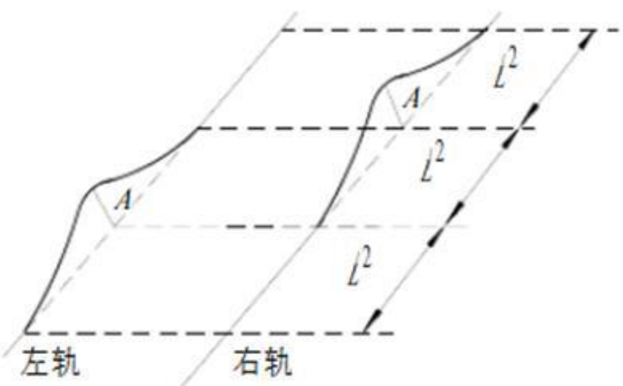


图 10.26 水平测量原理

Twist



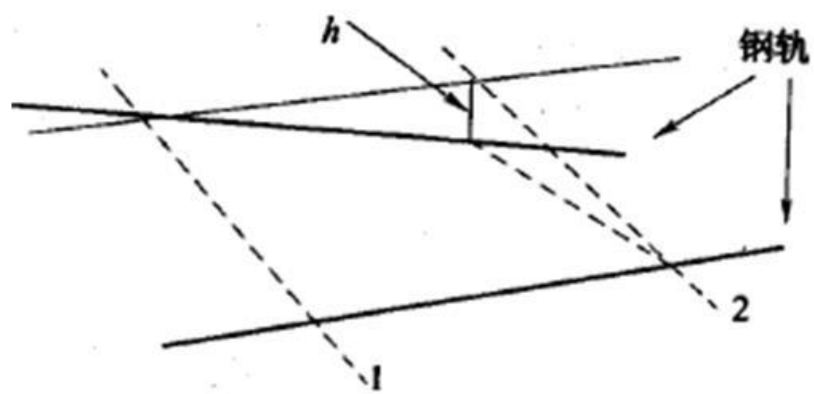


图 10.27 三角坑测量原理

Vibration

- Vehicle body vertical and lateral acceleration
  - Assessing track irregularity and comfort
  - Vibration frequency small, range big
- Alex box acceleration
  - Steel wheel and noise
  - Frequency big, range small
-

Track structure parameters

- Flying ballast cause rail surface damage
- Track clip loose
- Tie damage

Steel wheel force measurement

- Assess vehicle running smoothness and safety
- Lateral force: Q
- Vertical force: P

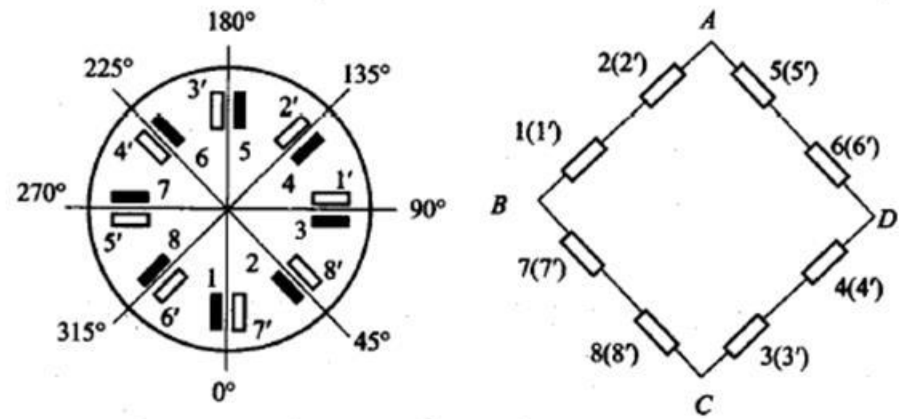


图 10. 28　横向力测量的应变片安装位置与电桥构成

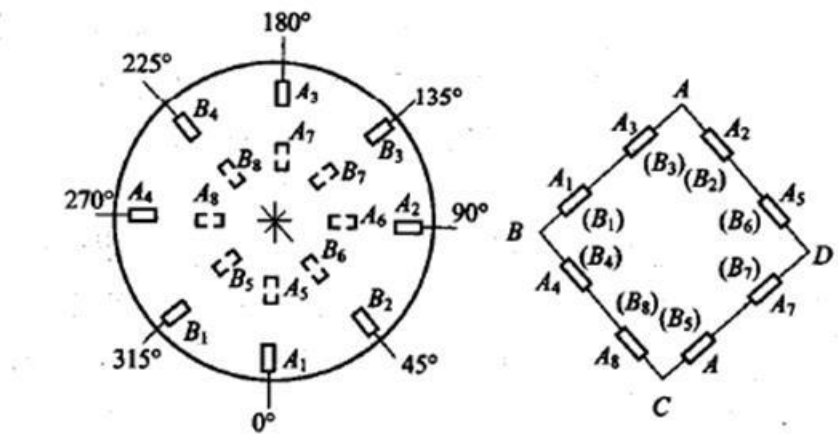
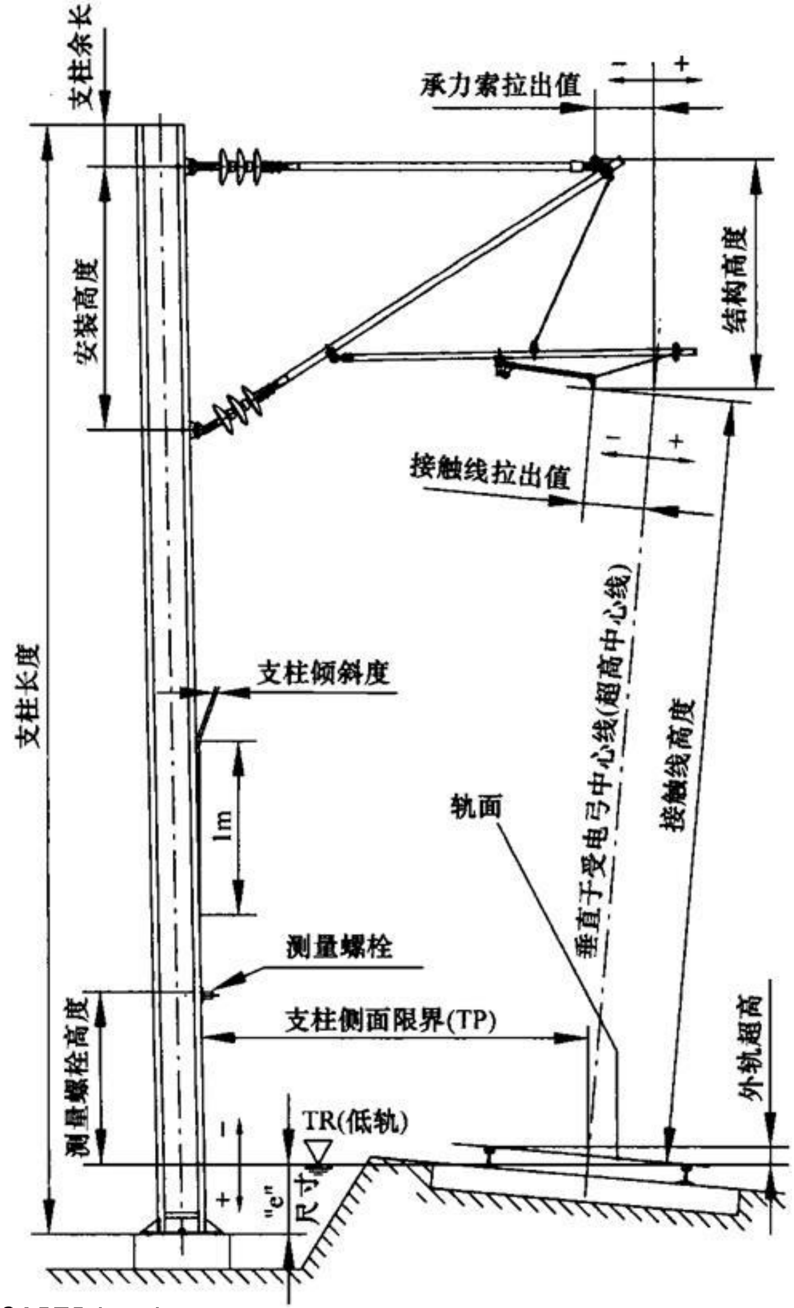


图 10. 29　垂向力测量的应变片安装位置与电桥构成

Catenary and pantograph inspection

- Catenary wire wear and tear
- Catenary high
- Catenary height change rate
- Wire extension
- Hard point and impact point
- Contact force between catenary and pantograph
- Contactless time
- Horizontal distance between wire
- Vertical distance between wires
- Pantograph voltage
- Current to vehicle
- Position device slope
- Distance between pole

Wire extension



- http://www.tielu.cn/baike/91872.html

Catenary and pantograph measuring

- Triangular photograph measuring system

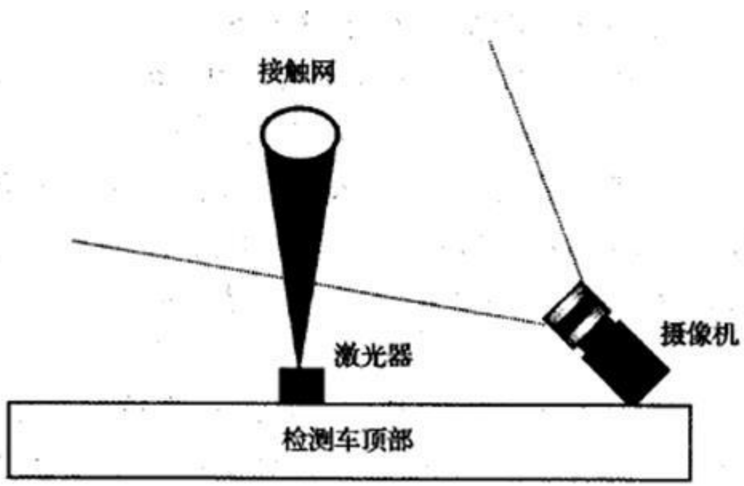


图 10.30　接触网几何检测原理

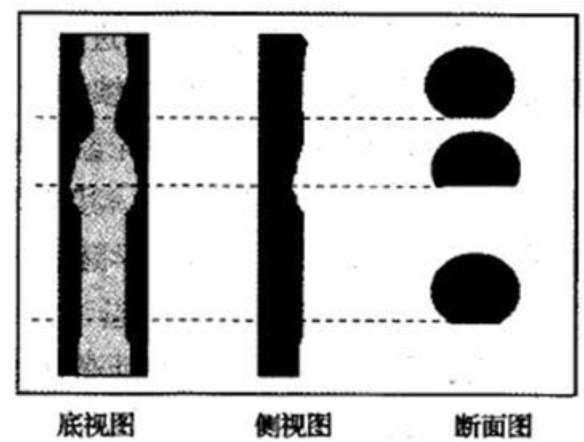


图 10.31　接触网导线磨耗

Sensors on pantograph

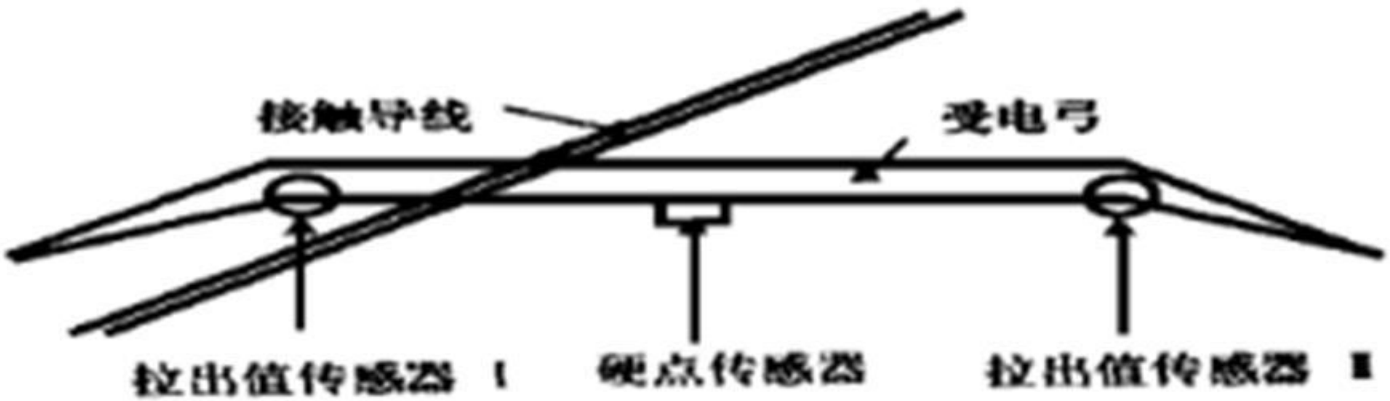


图 2 拉出值与硬点冲击超限检测传感器的安装位置

- http://www.doc88.com/p-5973045063865.html

Telecommunication inspections

- Wireless coverage along rail line
- GSM-R digital mobile communication system operation characteristics
- Train wireless dispatching information transmission characteristics
- Train operation control information transmission characteristics
- Wireless interruption along rail line

Telecommunication inspections

- Testing data collection, process and analysis
- Testing accessory system devices

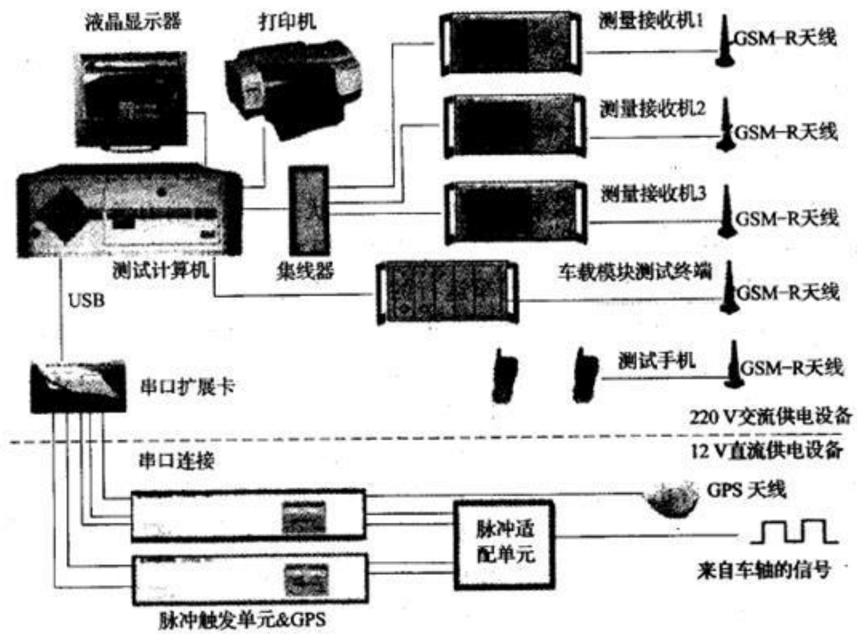


图 10.32 无线通讯检测系统构成

Signal inspection

- Rail electricity return
- Rail track circuit
- Locomotive signal display
- Point information collection
- GSM-R information receiving

Comprehensive analysis

- Data collection from different units
- Share
- Real time

Other Maintenance

- Rail flaw detection
  - Ultrasonic detector

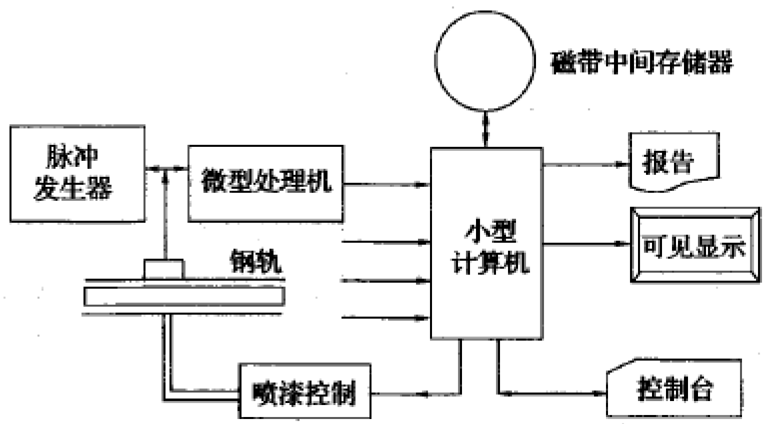


图 10.37 钢轨损伤检测车示意图

- Rail temperature monitoring

- Long bridge monitoring
  - Loading, column
  - Accelerometer,

Environment safety warning

content

- Wind
- Rain
- Earthquake
- Snow

Wind

表 10.8 京沪高速铁路强风管制建议

风速(m/s)	不设挡风墙		设置一定标准的挡风墙
	向曲线外侧	向曲线内侧	
<25	注意观察	列车限速 200 km/h	不加限制
25≤风速<30	列车限速 200 km/h	列车限速 80 km/h	注意观察
30≤风速<35	列车限速 80 km/h	停运	列车限速 200 km/h
≥35	停运	停运	列车限速 80 km/h

Rain

- Rain based monitoring system
- Three level operation regulation: vigilance, reduce speed and stop
- Sensors: camera, grade measuring, etc.

Earthquake

- Detect earthquake
- Cutoff power
- Stop train
- Strop train in contiguous sections

Snow

- Detect the snow fall, the depth of snow
- Impact the bottom of the train
- Impact the infrastructure next track

Maglev

- Maglev (derived from magnetic levitation) is a transport method that uses magnetic levitation to move vehicles without making contact with the ground
- The power needed for levitation is typically not a large percentage of its overall energy consumption; most goes to overcome drag
- maglev systems have been much more expensive to construct, offsetting lower maintenance costs.

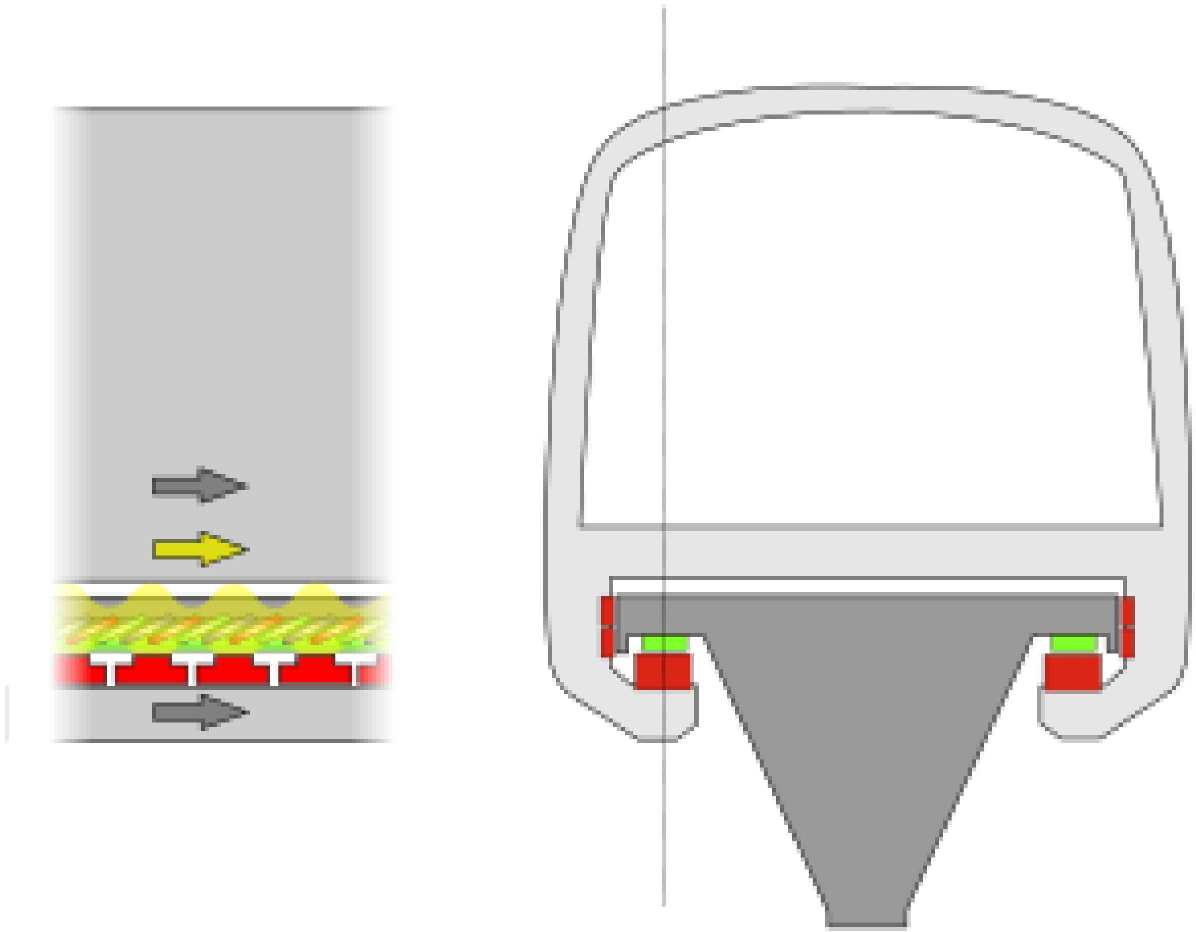
Maglev is in operation in 3 countries

- German:
- Japan:
  - relatively low-speed HSST "Linimo" line in time for the 2005 World Expo
  - a new high speed maglev line, the Chuo Shinkansen is planned to become operational in 2027
- South Korea: Incheon Airport Maglev
- China: Transrapid in Shanghai was primarily based on German technology

Two notable types of maglev technology

- Electromagnetic suspension (EMS)
- Electrodynamic suspension (EDS)
- youtube https://www.youtube.com/watch?v=EbORQVttbeU

Electromagnetic suspension (EMS)

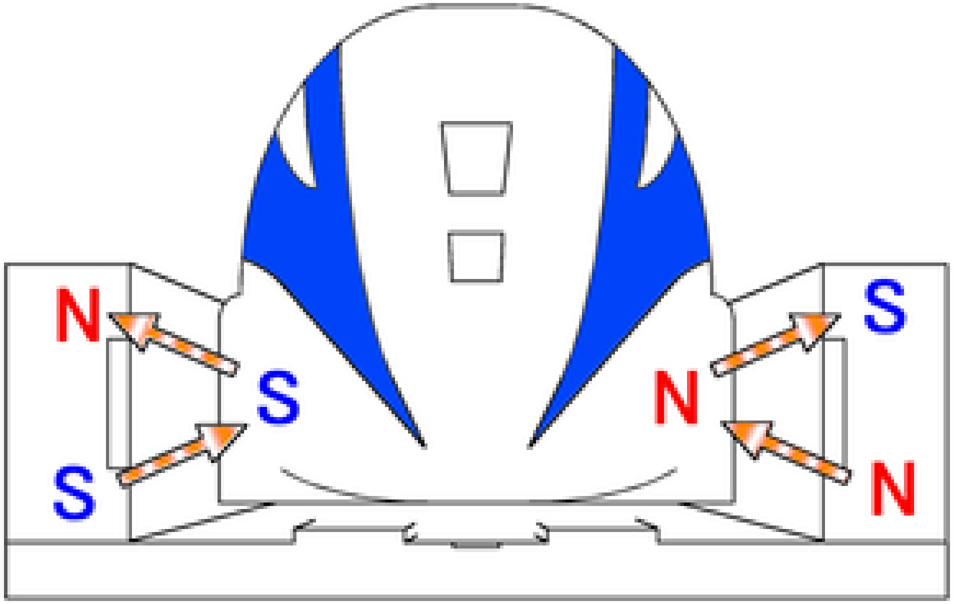


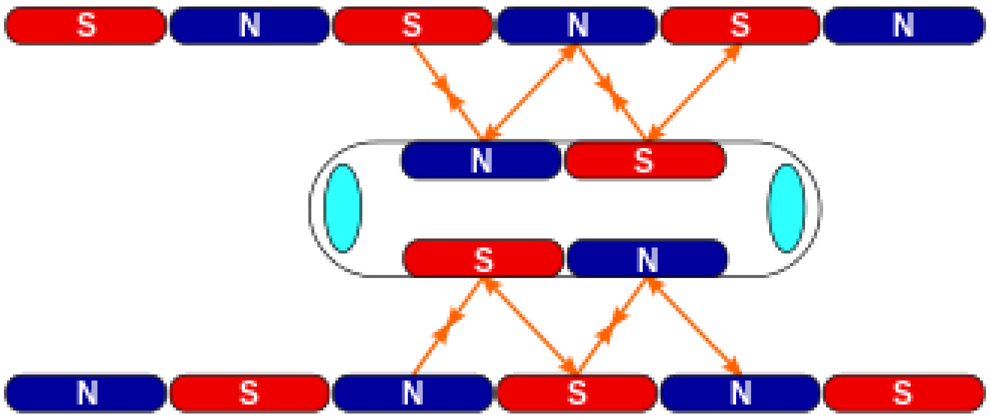
- https://en.wikipedia.org/wiki/Maglev

Electromagnetic suspension (EMS) (cont.)

- Pros:
  - They work at all speeds
- Cons:
  - Magnetic attraction varies inversely with the cube of distance, requiring sophisticated feedback systems to maintain a constant distance from the track

Electrodynamic suspension (EDS)





Electrodynamic suspension (EDS) (cont.)

- Pros:
  - Dynamically stable – changes in distance between the track and the magnets creates strong forces to return the system to its original position.
  - The attractive force varies in the opposite manner, providing the same adjustment effects. No active feedback control is needed.
- Cons:
  - The train must have wheels or some other form of landing gear to support the train

Tracks

- The term "maglev" refers not only to the vehicles, but to the railway system as well, specifically designed for magnetic levitation and propulsion.
- All operational implementations of maglev technology make minimal use of wheeled train technology and are not compatible with conventional rail tracks.
- Because they cannot share existing infrastructure, maglev systems must be designed as standalone systems.

Propulsion

- EMS systems such as HSST/Linimo can provide both levitation and propulsion using an onboard linear motor.
- But EDS systems and some EMS systems such as Transrapid levitate but do not propel. Such systems need some other technology for propulsion. A linear motor (propulsion coils) mounted in the track is one solution. Over long distances coil costs could be prohibitive

Stability

- Because maglev vehicles essentially fly, stabilization of pitch, roll and yaw is required

Guidance system

- When the vehicle is in the straight ahead position, no current flows, but any moves off-line create flux that generates a field that naturally pushes/pulls it back into line.

Energy use

- Most of the energy is needed to overcome "air drag". Some energy is used for air conditioning, heating, lighting and other miscellany.
- At low speeds the percentage of power used for levitation can be significant, consuming up to 15% more power than a subway or light rail service.
- For short distances the energy used for acceleration might be considerable.

Systems

- Test tracks
- Operational systems
- Maglevs under construction
- Proposed maglev systems

HSR Planning – Case studies

Two Case Studies

- UIUC and UIC (2013) conducted a preliminary feasibility study on the high speed rail in the Midwest area that connects Chicago, St. Louis, and Indianapolis
- The ridership for the California High Speed Rail was forecasted by Cambridge Systematics in 2005

220 Mph High Speed Rail Preliminary Feasibility Study

Travel Time Estimates (in minutes) between Chicago O'Hare International Airport and Lambert-St. Louis International Airport via Champaign

Southbound Exp.	*Southbound* Local		Miles	Station		*Northbound* Local	*Northbound* Exp.
0	0	Dp	0	O'Hare International Airport	Ar	154	140
10	10		16	Chicago Union Station		142	128
	28		47	University Park		124	
	40		72	Kankakee		112	
55	65		145	Champaign-Urbana		87	83
	84		193	Decatur		68	
88	102		233	Springfield		50	50
127	141		330	St. Louis Downtown		10	10
140	154	Ar	343	Lambert - St. Louis International Airport	Dp	0	0

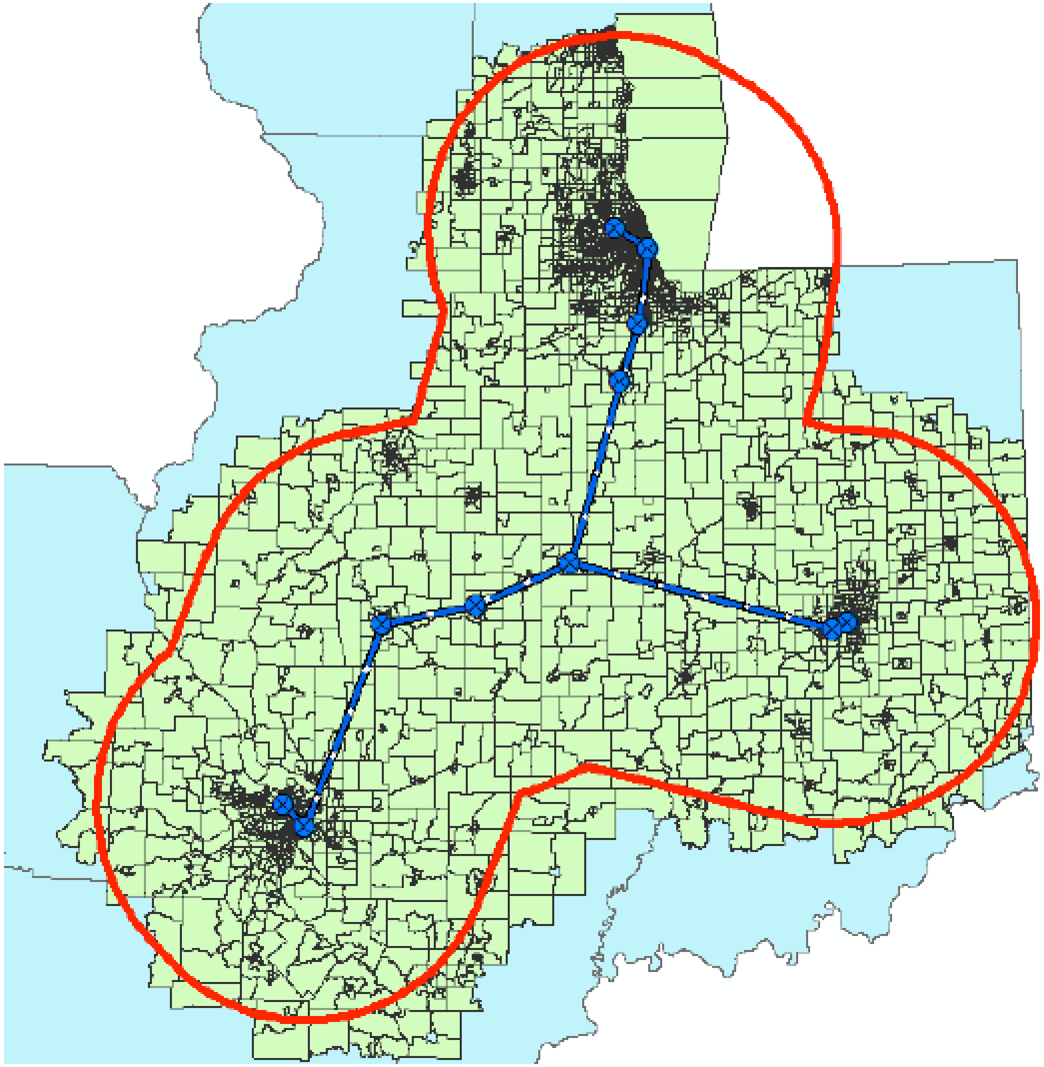
Travel Time Estimates (in minutes) between Chicago O'Hare International Airport and Downtown Indianapolis via Champaign

Southbound Exp.	*Southbound* Local		Miles	Station		*Northbound* Local	*Northbound* Exp.
0	0	Dp	0	O'Hare International Airport	Ar	140	127
10	10		16	Chicago Union Station		128	115
	28		47	University Park		111	
	40		72	Kankakee		98	
55	65		145	Champaign-Urbana		73	70
	84		184	Danville		55	
117	131		280	Indianapolis International Airport		8	8
127	140	Ar	290	Indianapolis Downtown	Dp	0	0

Methodoloy

- UIUC and UIC (2013) conducted a preliminary feasibility study on the high speed rail in the Midwest area that connects Chicago, St. Louis, and Indianapolis.
- To estimate the ridership, this study developed an inter-regional trip model from which trips between stations in the Midwest high speed rail network can be estimated and forecasted.
- Surveys were conducted to travelers of different modes from which mode share models were developed.
- The station-to-station trips can be assigned to different modes of transportation including high speed rail.

Ridership Study Boundaries



Projected 2035 HSR Ridership – Driving Cost 50 Percent Higher

2035 High Driving Cost Annual Riders (000s)	O'Hare	Union Station	University Park	Kankakee	Champaign	Indianapolis metro	Decatur	Springfield	St. Louis metro	Total
O'Hare		560	9	11	362	948	239	459	954	3,541
Union Station	560		239	9	201	463	54	206	501	2,233
University Park	9	239		23	77	306	57	129	250	1,090
Kankakee	11	9	23		7	63	3	13	71	199
Champaign	362	201	77	7		91	5	23	117	882
Indianapolis metro	948	463	306	63	91		43	178	472	2,565
Decatur	239	54	57	3	5	43		3	43	447
Springfield	459	206	129	13	23	178	3		106	1,117
St. Louis metro	954	501	250	71	117	472	43	106		2,514
Total	3,541	2,233	1,090	199	882	2,565	447	1,117	2,514	14,588

Profit-and-Loss Estimates, Maximum Baseline Revenues

YEAR	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Alternative 1 (Chicago – St. Louis), Low Capital Expenditures (Mostly Ballasted Track)										
Total Revenues	$536,287	$562,381	$589,825	$618,693	$649,063	$681,019	$714,648	$750,043	$787,301	$826,528
Total Operating Exp, Incl. Deprn	$692,757	$699,062	$703,851	$713,478	$722,643	$728,327	$739,547	$750,346	$757,138	$770,482
Total Operating Exp, Excl. Deprn	$162,748	$169,053	$173,842	$183,469	$192,634	$198,308	$209,606	$220,406	$227,198	$240,552
Net Income Excluding Deprn	$373,539	$393,328	$415,982	$435,223	$456,429	$482,711	$505,042	$529,637	$560,103	$585,975

California High Speed Rail

Demand forecasting

- According to an Independent Peer Review (2011), the ridership for the California High Speed Rail was forecasted by Cambridge Systematics in 2005.
- Because the proposed California HSR is large in scale, models for intra-regional travel and inter-regional travel were developed.
- The model for intra-regional were adopted from the existing travel demand models for San Francisco, Los Angeles, and San Diego.
- The model for inter-regional travel consists of models for trip frequency, destination choice, mode choice, and assignment.
- The choice model was developed based on their stated and revealed preference surveys to travelers at airports, rail stations, on-board trains, and phone interview.

Survey

20. Which <u>High Speed Rail station</u> do you think you would use to start your trip?

- Downtown San Francisco ☐
- Millbrae (SFO) ☐
- Palo Alto/Redwood City ☐
- Downtown San Jose ☐
- Gilroy ☐
- Downtown Oakland ☐
- Oakland Airport ☐
- Fremont/Union Cty ☐
- Pleasanton ☐
- Sacramento ☐
- Stockton ☐
- Tracy ☐
- Modesto ☐
- Merced ☐
- Fresno ☐

21. How do you think you would get to that station?

- Drive and park ☐
- Rental Car ☐
- Get dropped off/picked up ☐
- Taxi/shuttle ☐
- Bus ☐
- Train ☐
- Walk ☐
- Other ____________

22. About how long do you think it would take you to get to the station?

____________ minutes

I have no idea ☐

23. And about how much do you think it would cost to get to the station? (Please estimate costs <u>including fares, gas</u>, etc., but <u>not</u> including parking or rental car costs)

$____________

I have no idea ☐

24. At which station do you think you would get off the train?

- LA (Union Station) ☐
- Downtown Burbank ☐
- Ontario Airport ☐
- Riverside ☐
- Temecula Valley ☐
- Palmdale/Lancaster ☐
- Sylmar/S. Fernando Vly ☐
- Norwalk ☐
- Anaheim ☐
- Irvine ☐
- E. San Gabriel Vly ☐
- Escondido ☐
- University City ☐
- San Diego ☐
- Bakersfield ☐

25. How do you think you would get from that station to your destination?

- Drive and park ☐
- Rental Car ☐
- Get dropped off/picked up ☐
- Taxi/shuttle ☐
- Bus ☐
- Train ☐
- Walk ☐
- Other ____________

26. About how long do you think it would take you to get from the station to your destination?

____________ minutes

I have no idea ☐

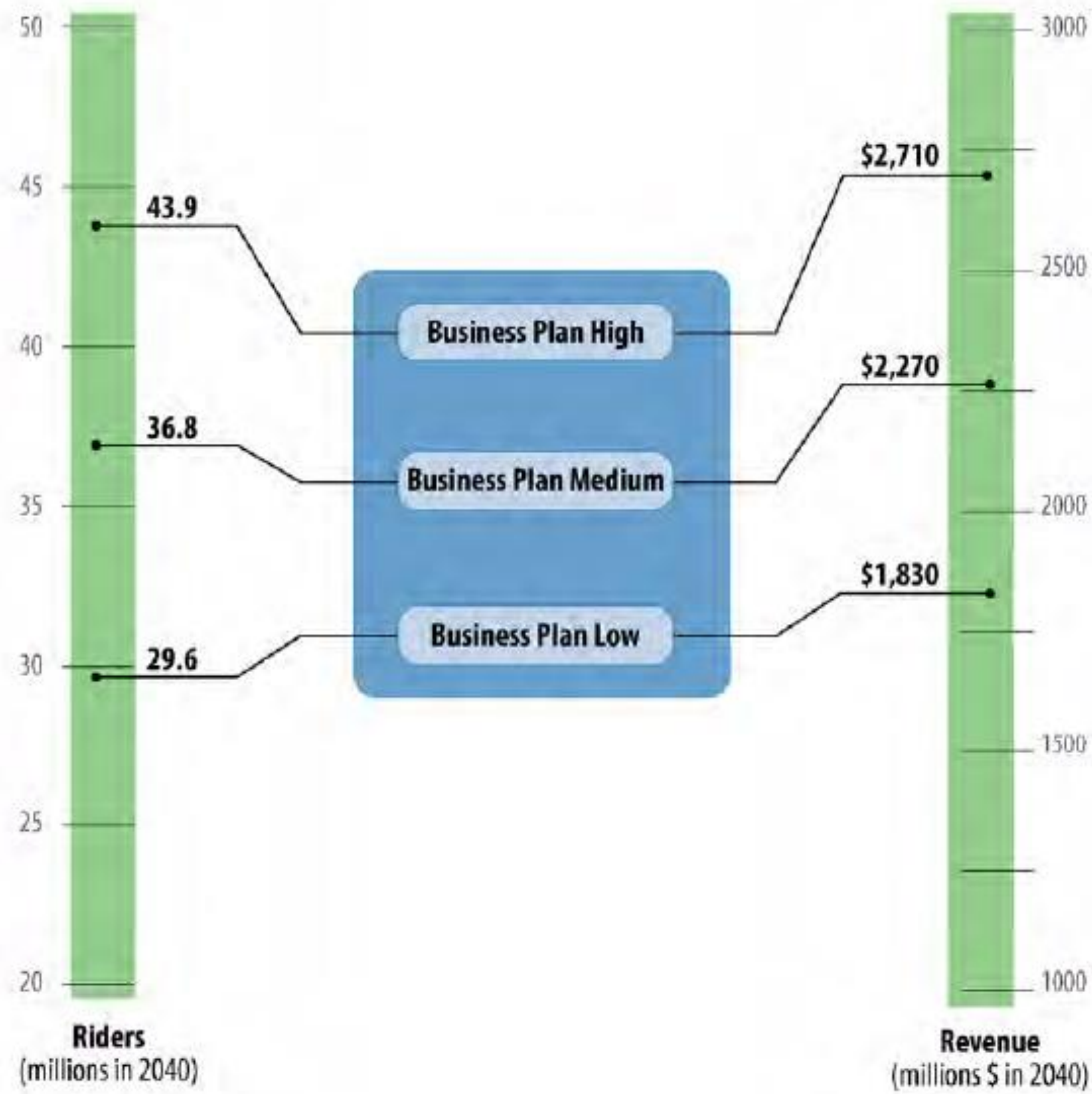
27. And about how much do you think it would cost to get from the station to your destination? (Please estimate costs <u>including fares, gas</u>, etc., but <u>not</u> including parking or rental car costs)?

$____________

I have no idea ☐

Survey (cont.)

- Total number of completed retrieval surveys: 1,507.
- Retrievals by origin region: San Diego (158), Los Angeles (243), Bakersfield (144), Tulare/Visalia (98), Fresno (149), Merced (155), SF Bay (283), Modesto/Stockton (144), and Sacramento (133).



50
45
40
35
30
25
20
43.9
36.8
29.6
Business Plan High
Business Plan Medium
Business Plan Low
$2,710
$2,270
$1,830
3000
2500
2000
1500
1000
Riders
(millions in 2040)
Revenue
(millions $ in 2040)

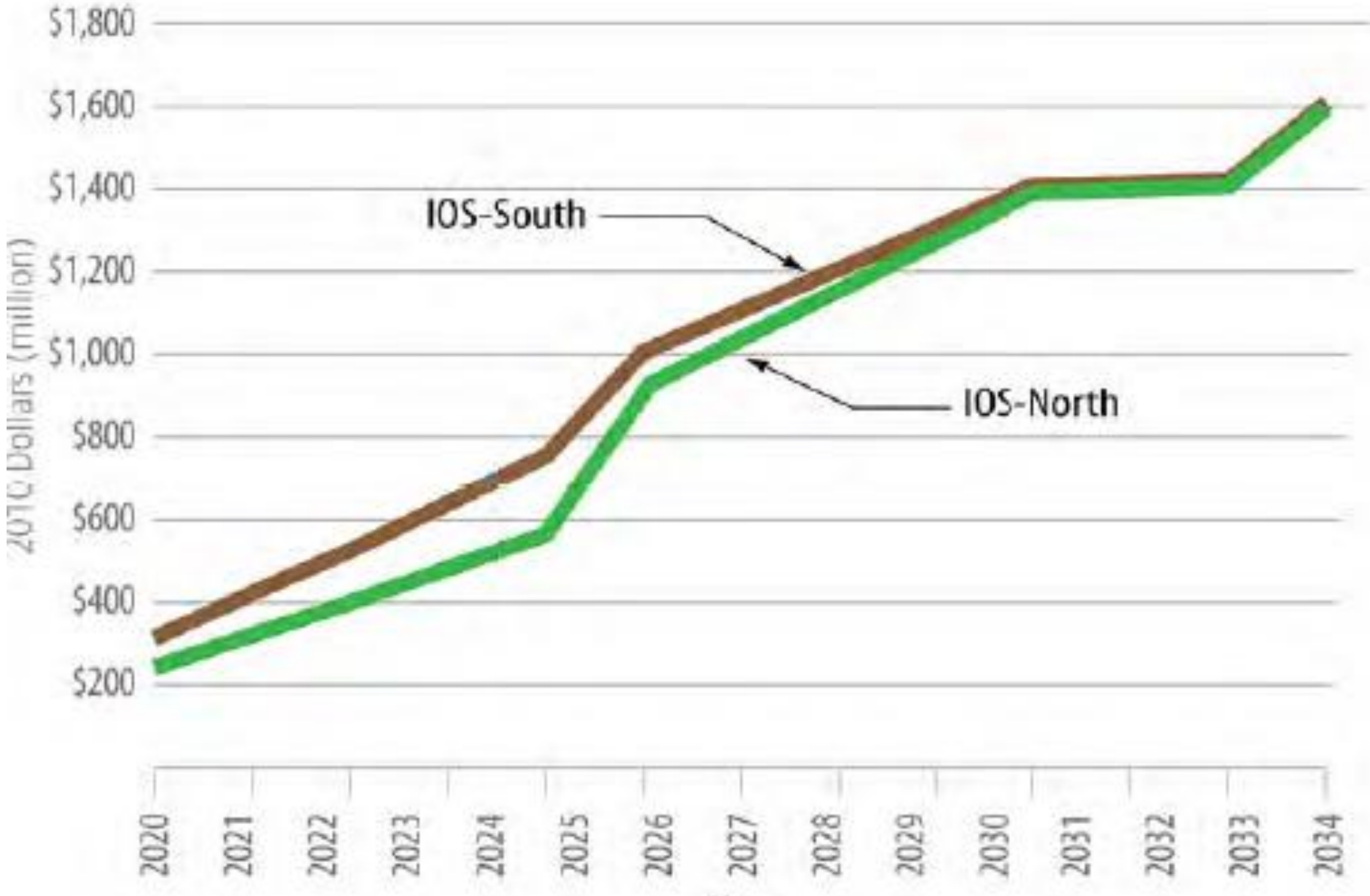

$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
2010 Dollars (million)
IOS-South
IOS-North
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034

Exhibit 7-6. O&M cost ranges, IOS-North first through Full Phase 1 (2010 dollars in millions)

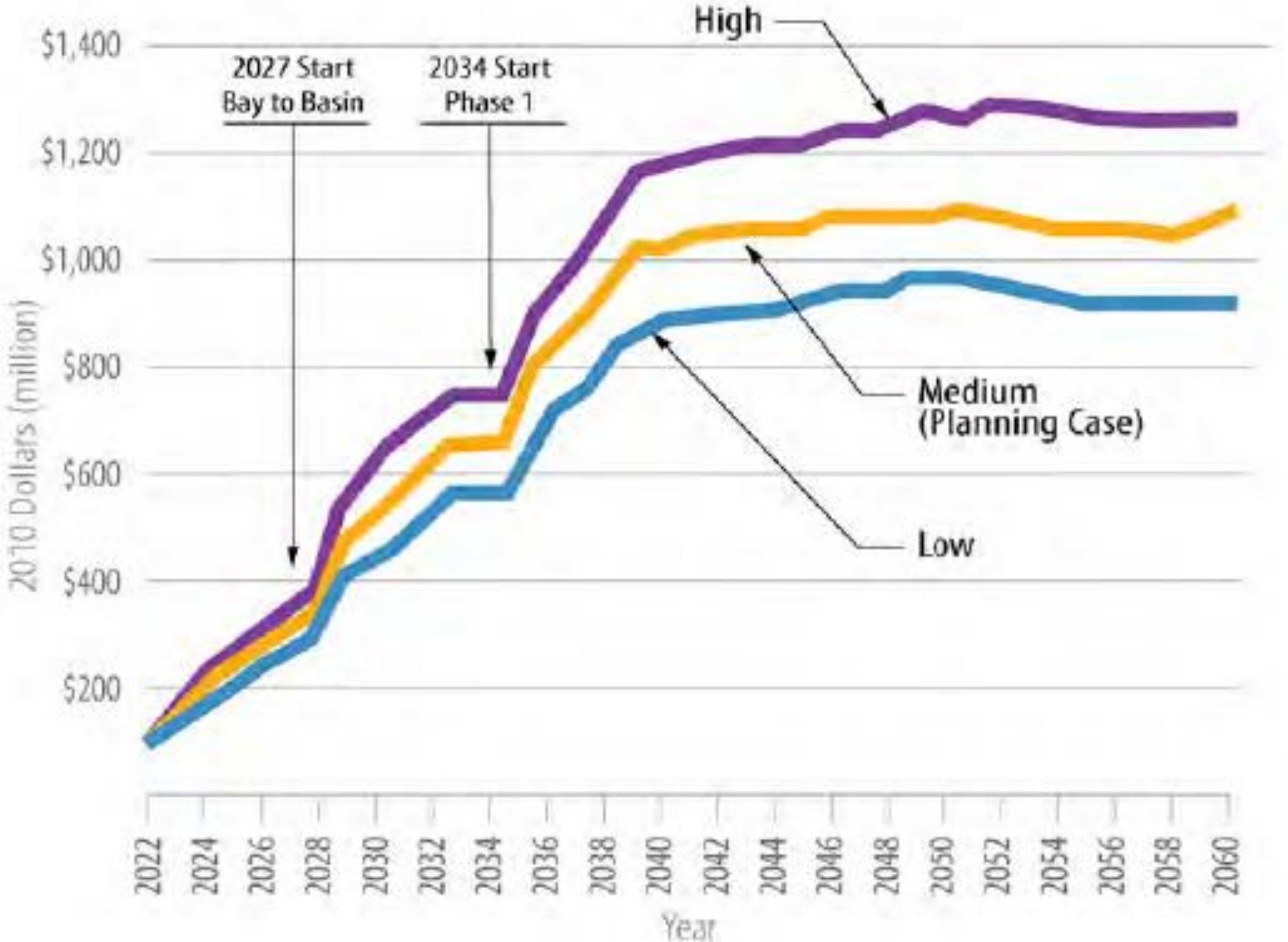


Exhibit 7-8. O&M cost ranges, IOS-South first through Full Phase 1 (2010 dollars in millions)

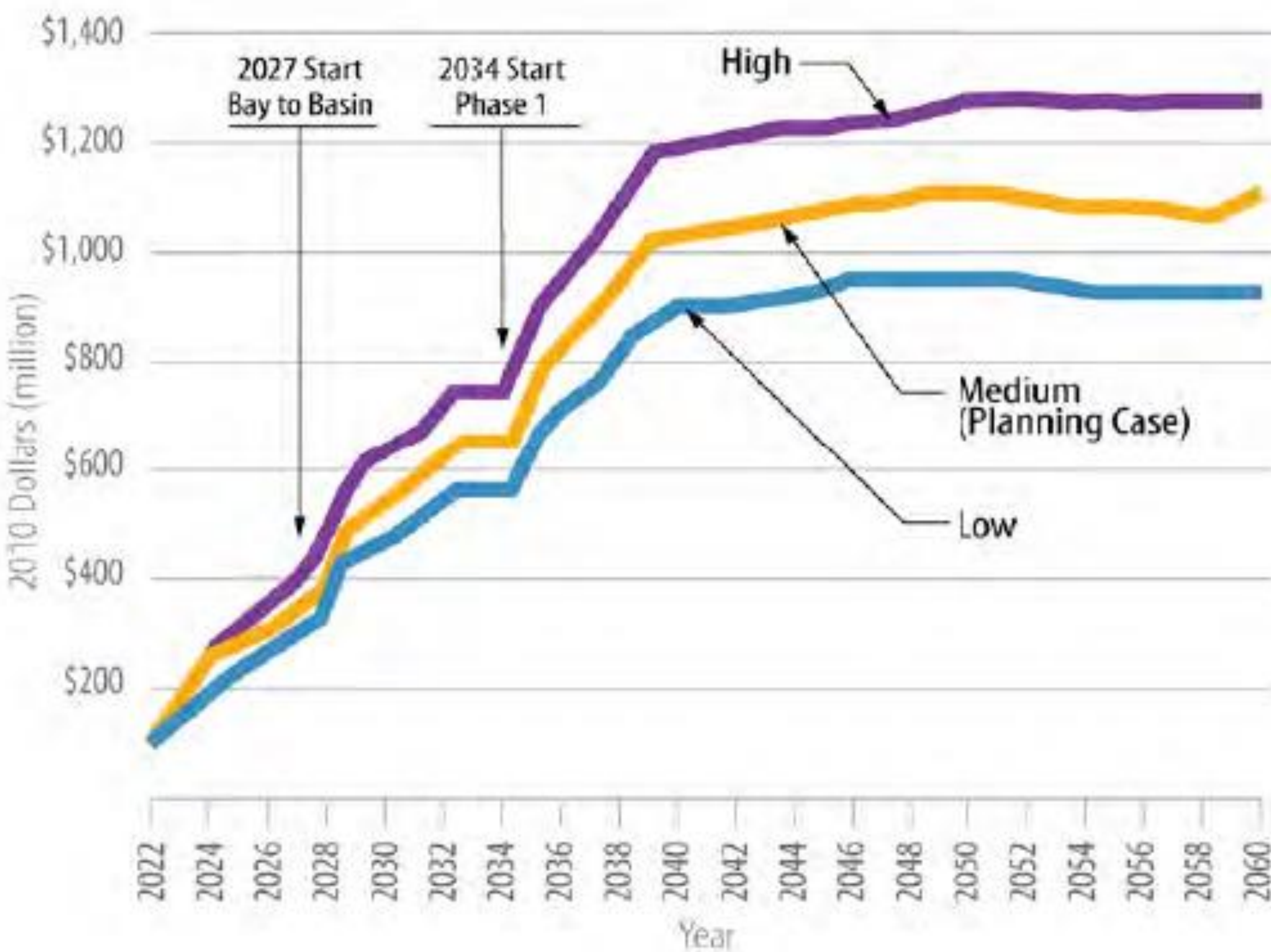


Exhibit 8-1. Capital costs IOS-North alignment—2010 dollars and year-of-expenditure dollars in millions