

INNOVATIONS FOR RESURGENCE OF RAILWAY SERVICES IN USA

Dr. M. Ali Khan, M.Phil., PH.D., D.I.C.
P.E., MASCE, MICE England
Chartered Engineer

1. INTRODUCTION AND DEFINITION OF THE PROBLEM

- **Repeated journeys by train:** In most cities, traffic is a disaster since roads cannot be made wide enough.
- Railways offer extensive travel by land.
- Due to safety concerns of civil and structural infrastructure, they are expensive to build and maintain. Compared to the highway structures, railways have heavier superstructure with heavier foundations, resulting from much heavier freight.
- There are thousands of miles of tracks, ballast, embankment, ties and signals, depots, yards, railway stations, noise walls & car parks as required.

- AREMA Code has 4 heavy volumes compared to one heavy AASHTO volume. Design, construction, research and operation can create thousands of jobs for both engineers & non-engineers.
- Revenues obtained from trains are greater from goods than from passengers. Both are equally beneficial for the community.
- Deficiencies or malfunction of any of the tracks can shut down the train service affecting commuters and delivery of goods.
- **Need for railways:** In many places, highways have reached their full capacity leading to traffic jams and environmental pollution. Introducing more railways for transportation can limit the problems by reducing traffic delays & by increasing comfort.

REASONS FOR THE SLOW PROGRESS SO FAR

The greater the density of population, the greater the need for railway system, which is timewise feasible up to 500 miles travel using fast trains, except for freight transfer which is more important than passenger travel.

Only certain cities and coastal regions are densely populated making use of railways economically possible.

In the past, there was stiff competition from car manufacturers for promoting investments since the time of Henry Ford, and the airline companies and railways could not expand.

Luxury trains can promote vacation travel and sightseeing.

EARLIER DIFFICULTIES CAUSED BY NETWORK FAILURES

Comparison of AASHTO AND AREMA CODES/ FHWA VS. FRA Regulations: AREMA Code has 4 volumes compared to one AASHTO volume.

- Train loads on tracks are many times higher than truck or lane loads. A comparison between AASHTO and AREMA live loads is attached files.

- Hurricanes, seismic and floods combinations are to some extent similar. The major differences are in the intensity of live loads, fatigue analysis centrifugal forces and load combinations.

Traction is sensitive and confined to 2.75 inch top width of rail flange. Please see attachments. Stability concerns leading to overturning may occur on curved rails due to high centrifugal forces and at high speeds.

- In many places the highways have reached their full capacity and there are traffic jams and environmental pollution. Introducing more railways for transportation can limit the problems by reducing traffic delays and by increasing comfort. Inspections of the track need to be frequent.

- Movable bridges located on rivers require higher head room than 23 ft. for ships to pass and operation cost increases.
- Replacements and retrofits are required due to corrosion and fatigue, resulting from repeated usage and old age train infrastructure.

● AESTHETIC CONSIDERATIONS

The type of railway bridge to be selected will depend upon aesthetics and the span length using,

- Steel or Prestressed Concrete Girder Bridge, for small and medium spans
- Box Bridge
- Truss Bridge, for medium spans
- Arch Bridge, for medium spans
- Segmental Prestressed Concrete, for long spans
- Cable Stayed Bridge, for long spans
- Suspension Cable Bridge for very long spans

Environmental permits will be required after selection of bridge geometry and preliminary design.

RAILWAY STRUCTURES INCLUDE

- Bridges/Tunnels,
- Culverts and Retaining walls etc.
- Each requiring special design criteria and software.

There are 3 types of design processes:

- Conceptual design (to select bridge type),
- Preliminary design (based on value engineering) and
- Final design (checked by independent engineer) before contract documents such as drawings, specifications and schedule are prepared.
- Conceptual design can also be used to check the computer output and the results for deflections, forces and moments from software analysis results.

ESSENTIAL COMPONENTS

A standard rail section is attached.

Common rail spacings are:

- Narrow gage,
- Broad gage,
- Standard gage,
- Special gage.

In USA, Standard gage of 4ft 8.5 inches is commonly used.

The number of tracks and the gage distance will determine the width of the bridge.

Deck slab and connections with the ties are also attached.

STUDYING BRIDGE FAILURES

A. Common structural damages,

1. Material Failure,
2. Abutment Cracking, Movement, Settlement Of Pier
3. Skew Effects,
4. Foundation On Expansive Soils,
5. Unknown Foundations,
6. Defects In Concrete Arches.

B. Modifying AREMA CODE design criteria,

C. Inadequate Precautions and solutions.

MODES OF FAILURE FOR STEEL BRIDGES (AREMA Chapter 15)

1. BENDING TENSION STRESS IN A MEMBER IS EXCEEDED DUE TO LONG TERM FATIGUE.
2. SHEAR STRESS OR PRINCIPAL TENSILE STRESS IS EXCEEDED AT GIRDER SUPPORTS.
3. FAILURE OF BOLTS OR WELDS AT JOINTS.
4. LOCAL BUCKLING OF COMPRESSION MEMBERS,
5. INCREASED THERMAL STRESS IN MEMBERS DUE TO MALFUNCTION OF EXPANSION BEARINGS
6. FOUNDATION MOVEMENT DUE TO SCOUR DURING FLOODS LEADING TO SETTLEMENT OF PIER OR ABUTMENT.

MODES OF FAILURE FOR CONCRETE BRIDGES (AREMA 2017,Chapter 8)

1. DEFICIENCIES IN MIX DESIGN OR IN HOT AND COLD WEATHER CONCRETING PROCEDURES.
2. CORROSION OF REINFORCING BARS OR PRESTRESSING TENDONS.
3. CRACKING AT ANCHORAGES DUE TO HIGH PRINCIPAL TENSILE STRESS.
4. LOSS OF PRESTRESS FORCES,
5. LACK OF PROVISION OF THERMAL, SHRINKAGE AND CREEP STRESS IN DESIGN.
6. SHEAR STRESS OR PRINCIPAL TENSILE STRESS IS EXCEEDED AT GIRDER SUPPORTS,
7. FOUNDATION MOVEMENTS DUE TO SCOUR DURING FLOODS LEADING TO SETTLEMENT OF PIER OR ABUTMENT.

USE OF MODERN TECHNOLOGY IN PLANNING NEW OR REPLACEMENT BRIDGES TO MINIMIZE COSTS

1. Direction of abutment skew should be made parallel to direction of river flow, to minimize scour,
2. Based on hydraulic analysis, opening size is increased to minimize overtopping flood using HEC-18 procedures,
3. Use of Integral abutments and integral approaches make the bridge highly resistant to longitudinal forces,
4. Steel girders replaced by prestressed spread box beams to prevent corrosion,
5. Use of deep sheet piling sections to minimize scour of abutment and wingwalls.

BRIDGES ON WATERWAYS HAVE THE FOLLOWING PROBLEMS

IN USA, OVER THIRTY SIX THOUSAND BRIDGES ARE EITHER SCOUR CRITICAL OR SCOUR SUSCEPTIBLE.

1. THERE ARE RESTRICTIONS FROM ENVIRONMENTAL AGENCIES, IN PLACING PIERS IN RIVER BEDS RESULTING IN LONGER SPANS.
2. DIFFICULT TO DESIGN AND CONSTRUCT DEEP FOUNDATIONS IN FLOWING WATER.
3. DIFFICULTIES IN MAINTAINING BRIDGE SUBSTRUCTURE UNDERWATER AND IN REGULAR PAINTING OF CORRODED GIRDERS.

4. **SOME EXAMPLES OF RECENT BRIDGE FAILURES ARE**

- SCHOHARIE CREEK BRIDGE LOCATED ON NY STATE THRUWAY IN 1987
- US 51 BRIDGE OVER HATCHIE RIVER IN TN IN 1989
- DAMAGES TO BRIDGES LOCATED ON MISSISSIPPI RIVER IN 1993
- INTERSTATE 5 NB AND SB BRIDGES OVER LOS GATOS CREEK IN CA IN 1995
- ROUTE 46 BRIDGE ON PECKMAN'S RIVER BRIDGE IN PASSAIC COUNTY IN NJ IN 1998
- OVILLA ROAD BRIDGE LOCATED IN ELLIS COUNTY IN TX IN 2004.

EXISTING LIGHT TRANSIT SYSTEMS

- The NYC Subway
- Staten Island Railway
- Chicago L Red and Blue Lines
- Minnesota Metro Transit Green Line
- PATCO Line Connecting South Jersey and Philadelphia
- River Line Connecting Camden and Trenton
- The Long Island Rail Road (LIRR) will replace the railroad's 103-year-old Post Avenue Bridge that carries the Main Line over Post Avenue at the Westbury train station.

MAJOR PROJECTS IN HAND

Two American railway companies are among the top six in the world namely CSX and Union Pacific in terms of revenue. The rest 4 are Japanese, Chinese & French.

- Amtrak Ready to Build Projects on Northeast Corridor (between Boston and Washington DC) include:
- Baltimore & Potomac Tunnel
- Hudson Tunnel Project, NY
- Portal North Bridge Project
- Susquehanna River Bridge Project, MD
- Connecticut River Bridge Project, CT
- Niantic River Bridge Project, CT.

Where the terrain is varying, tunnels may be required in place of bridges.

1.

MAJOR STATIONS DEVELOPMENT IN HAND

These include:

1. New York Penn and Moynihan Stations
2. Philadelphia 30th Street Station
3. Baltimore Penn Station
4. Washington Union Station
5. Chicago Union Station

Importance Categories

- Critical Bridges : Must be open for all train traffic after the design earthquake and open to emergency trains after a large earthquake
- Essential Bridges : Must be open to restricted number of trains after the design earthquake
- Other Bridges : May be closed for repair after a large earthquake

DESIGN PROCESS

Bridge Substructure:

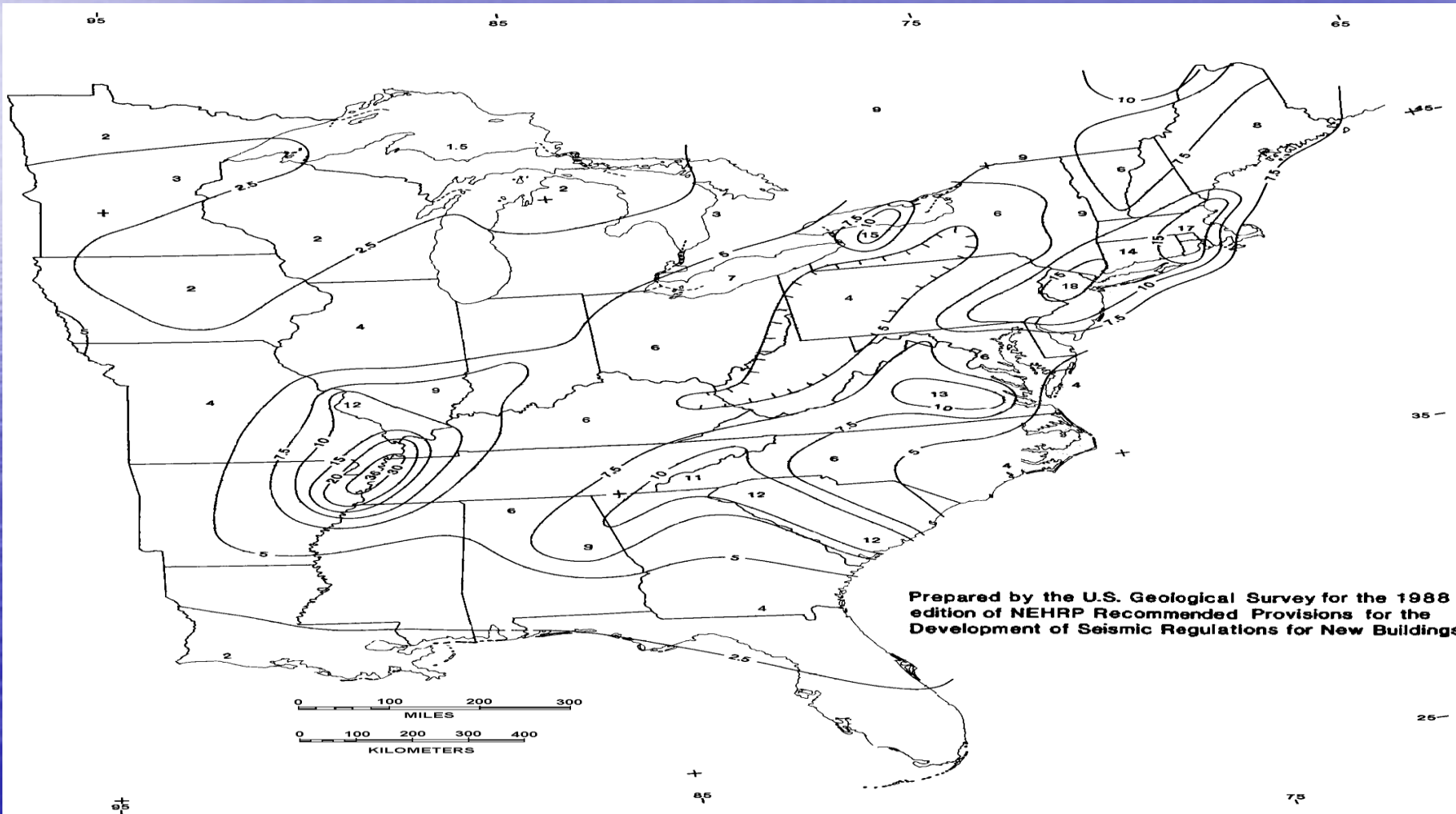
- Foundations; Spread or Deep
- Abutments; Integral Preferred
- Piers; Wide Enough to Accommodate 2 Rows of Bearings
- Bearings; Fixed, Sliding or Isolation.

Seismic Design parameters used in design

- Importance Categories
- Seismic Performance
- Site Coefficient
- Response Modification Factors

Seismic Performance

Acceleration Coefficient (A) The horizontal acceleration of an earthquake moving through ground



Seismic Performance

Acceleration Coefficient	Seismic Zone
$A \leq 0.09$	1
$0.09 < A \leq 0.19$	2
$0.19 < A \leq 0.29$	3
$0.29 < A$	4

Site Coefficient (S)

Type I ($S = 1.0$) : rock or rock with an overlying layer of stiff less than 200 ft deep

Type II ($S = 1.2$) : stiff clay layer exceeding 200 ft in depth

Type III ($S = 1.5$): soft to medium clay layer, at least 30 ft deep

Type IV ($S = 2.0$): soft clay or slit layer, exceeding 40 ft deep

Response Modification Factors (R)

- Reduce component seismic forces based on elastic analysis
- Recognizes that energy is dissipated through inelastic action during a design level event

METHODS TO ANALYZE AND DESIGN A BRIDGE FOR EARTHQUAKES (similar to highway bridge seismic analysis)

- UNIFORM LOAD METHOD
- SINGLE MODE SPECTRAL METHOD
- MULTIMODE SPECTRAL METHOD
- TIME HISTORY METHOD

1. INCENTIVES MUST BE GIVEN TO PUBLIC FOR WIDER USE OF TRAINS

Wider Investments Required:

- Benefits and comforts of train travel need to be further increased: Trains provide many benefits such as dining cars, sleepers, relaxation, vacation and sightseeing.

Lower Train Fares: Long distance train travel has competition with planes connecting major cities, for buses used for shorter distances; public using their own cars or renting cars. Current passenger fares are on the higher side and discourage the general public, the ability to catch trains.

- A program of monthly passes be adopted for reducing passenger time spending on purchase of daily tickets.
- **Frequency of train service:** More light transit trains need to be introduced between towns.
- **Excursion trains** to places of interest to be introduced to promote tourism, vacation travel and entertainment.
- **Other facilities** like dining halls, televisions and sleepers for long journeys of over five hours be provided.
- **Charges for goods transfer:** Unlike plane charges, freight accompanying the travelers be kept minimum.

PROPOSED EXPANSIONS IN INTERCITY TRANSIT

Camden to Glassboro (Rowan University)

Camden to Atlantic City

Camden to Wilmington Delaware

Western Philadelphia to Reading

Philadelphia Subway System (to reduce traffic congestion and parking difficulties).

- **PREVENTING TRAIN DELAYS:** Train delays caused by slippery rail conditions can be avoided on a daily basis. NJ Transit is utilizing its two AquaTrack machines to clean fallen leaves off its rails. AquaTrack equipment is a high-pressure power-washing system that removes leaves and oily residue from the tracks in an effort to prevent train delays caused by slippery rail conditions. operation runs from mid-October through mid-December.
- It consists of two 250-horsepower diesel-engine units mounted on a flat car with an operator control cab. Two pressure-pump units dispense water up to 20,000 pounds-per-square-inch, directly to the top of the rail.

- **The leaf clearing:** NJ Transit trims trees to help stem the amount of leaves on the tracks in the Fall.
- **INCREASING TRACTION:** Spreading sand on the rails in front of peak-period trains to increase traction is required.
- **EVACUATION DUE TO WILDFIRES:** As wildfires burn in its service region, Sonoma-Marín Area Rail Transit (SMART) will continue to provide free train service for passengers through Sunday, Oct.15 to assist evacuees and others who need transportation options.

- BNSF worked with WSDOT on the line between Blaine, Wash., near the U.S. Canadian border and Vancouver, Wash., to bring improvements, focused on enhancing passenger rail service and ensuring a consistent level of freight operations through the region.
- The seven-year program, which included five of heavy construction, was funded largely with \$800-million in American Recovery and Reinvestment Act (ARRA) High-Speed Intercity Passenger Rail funds.

- **Caltrans** will set strategic investments to create an easy-to-use rail system offering
- Faster and more frequent service,
- Customer-friendly timed multimodal connections,
- Integrated ticketing and trip planning, and increased reliability of travel in congested corridors around the state.
- The plan outlines a series of investments to connect most communities in California to each other at least every hour throughout the day, with many regions being connected with half-hourly service.

- It also highlights the critical role for the rail system to be expanded in its ability to move a growing volume of freight cleanly and efficiently.
- The plan will guide the state's priorities for rail investments that support California's economy for future generations.
- Public feedback is critical to ensure that the strategies developed reflect the diverse needs of all communities throughout the state.

● **FUNDING ISSUES AND POSITIVE ROLE OF P3**

- Amtrak's Large Projects at Present are at a Standstill.
- Large sum of monies and investments are required to maintain and develop railway industry. Railway agencies may not have large enough budgets.
- Government subsidies are a must and given top priority. In most cases railway agencies are privately owned.
- P3 (public-private-partnership) type of financing seems to have worked well and needs to be promoted.

RECOMMENDATIONS FOR PREVENTIVE AND DIAGNOSTIC DESIGN

1. A separate code for “Preventive and Diagnostic design” needs to be developed in keeping with LRFD Specifications, not currently allowed.
2. An accompanying rehabilitation construction code leading to “Selective Reconstruction” of potential damage to concrete or steel members or joints, based on fragility & vulnerability analysis is required. It should consider all failure modes in the light of failure analysis.

Advanced Inspection Techniques

For effective maintenance there is a need for Quality Control in inspection methods similar to that of aircraft structures.

At the time of construction, Remote Sensors at critical stress areas need to be installed and daily stress records be monitored not every two years.

EACH COOPER E-80 TRAIN WITH 4 AXLE LOADS:

Total 4 TRAINS as follows:

1. Front axle of 40 kips, followed by
2. First train with 4 axles of 80 kips each, spaced at 5 ft each and
3. Second train with 4 axles of 52 kips each spaced at 5,6,5 ft plus
4. Front axle of 40 kips, followed by
5. Third train with 4 axles of 80 kips each, spaced at 5 ft each and
6. Fourth train with 4 axles of 52 kips spaced at 5,6,5 ft each and
7. Total length between all axles = 104 ft.
8. Udl of 8kips/ft. located 5 ft. from last train axle.

Total axle load = 1136 kips with 8 and 9 ft. gap between 4 trains,
the trailing udl. of 8 kips/ft spaced at 5 ft. away.

(Please use the B.M. Table given on Page 157 of Unsworth text book or
AREMA).

B.M. due to alternate live load is simpler and can be calculated by first principles.

B.M.s for alternate 4-x 100 kips axle loads.

4 Traveling axle loads spaced at 5,6,5 ft. acting at midspan:

For Connecticut River Bridge, Max. $L = 180$ ft., $L/2 = 90$ ft.

For symmetry about center line, $a = 82$ ft, $b = 87$ ft. $P = 100$ kips

M (max) = $P \cdot a + P \cdot b$ (Magnitude for small spans is governing compared to E80)

(An analysis table for max. shear forces and bending moments is available for Cooper E80 movable loads based on span lengths in old AREMA)

Additional B.M. due to braking forces acting at 8 ft. need to be added as required by AREMA.

Cover plates on top and bottom flanges need to be added to make section compact resulting in greater head room than minimum 23 ft.

Girder moment of inertia I value can be increased significantly by providing composite action with deck slab by using shear connectors.

Above hand calculations can be used to check computer results (from STAAD-Pro).

USE OF COMPUTER SOFTWARE FOR ANALYSIS AND DESIGN 3-D geometric models for straight, skew and curved superstructure and substructure piers and abutments needs to be set-up and only selected approved software used. Methods of analysis and design can either be ASD for both steel and concrete and LFD for steel. So far LRFD has not been adopted by AREMA MRE although composite action between slab and beams is permitted for economic design. Design is made simpler by having simply supported boundary conditions for girders, although increasing the number of bearings but replacing only a small section of the bridge in emergency is possible rather than replace the entire continuous bridge.

Well known software though not based on latest AREMA 2017 CODE are:

BENTLEY, STAAD-pro is widely used. Besides bridge structures, it has modules for base plates, bolt groups, moment connections, retaining walls, spread and pile footings and MAT FOUNDATIONS, ETC.

CSI BRIDGE, SAP 2000

UNIVERSITY OF MARYLAND, MERLIN-DASH for design of steel, lateral bracing, fatigue details, minimum weight optimization and rating and LEAP SOFTWARE

1. STRUDL ORIGINALLY FROM GEORGIA TECH
2. RAM SOFTWARE
3. SEISAB for (single and multimode response spectrum) seismic analysis and soil and foundation properties
4. DESCUS FOR DESIGN OF CURVED GIRDERS AND BOX SYSTEMS
5. NY STATE 'BRADD' AND PENNDOT 'BRASS' PACKAGES, CONSPAN for prestressed concrete
6. Mathcad Professional for Extensive Computational Ability for Graphical Output
7. Culvert Program for Single or Multiple Cell Box for Small Span Reinforced Concrete Structure
8. Splices, Welds, Bolts and Special Connections Design Computer Programs Such as Scupper for Bridge Deck and Spliced Program, AISISPLICE for steel and consplice for concrete bridge girders
9. Other Softwares for use of Railway Bridges Include. Hydrology and Hydraulic Analysis Software Such As HEC_RAS, WSPRO, HEC-18 AND HEC-23 software for bridges on rivers.

AUTHOR'S EXPERIENCE IN TRANSIT TRAINS IN THE NORTHEAST; BRIDGES AND TUNNELS

1. Famous Victoria Line 15 ft. diameter Tunnel for in clay for London Underground
2. Septa 30th Street Station Reconstruction
3. Repainting of Benjamin Franklin Bridge with Bridge Steel Approaches
4. Maintaining PATCO Line over the Bridge
5. Replacing Schuylkill River Bridge
6. WMATA Overhead train to Dulles Airport
7. New Jersey Transit Car Park
8. 2 MBTA Bridges MP 0.79 and MP 1.36 near Boston.
9. 2 Intersections (Highways over Railways) in NJ.
10. Monfayette Expressway in Western PA and 23rd St. over LIRR.
11. Author of text book on railway engineering in progress.

HIGHWAY BRIDGES DESIGN IS NOT INCLUDED.

RECENTLY COMPLETED OR CURRENTLY IN CONSTRUCTION PROJECTS IN USA

- California has taken the lead with the Los Angeles to San Francisco fast train project.
- Other major projects are in Texas and
- The Northeast Amtrak initiative.
- **NJ:** \$1.5B project to replace critical New Jersey rail bridge over Hackensack River starts and create new capacity on the 10-mile stretch of the Northeast Corridor **between Newark and Penn Station New York.**
- **The Chicago Transit Authority (CTA) Board** approved the award of a design/build contract for the rehabilitation and upgrade of the Jefferson Park and Belmont Blue Line stations as well as the construction contract for the Green Line Garfield Gateway Project.
- **LIRR to replace Post Avenue Bridge:** The Long Island Rail Road (LIRR) will replace the railroad's 103-year-old Post Avenue Bridge that carries the Main Line over Post Avenue at the Westbury train station. according to the Metropolitan Transportation Authority (MTA).

NVTA's \$43 BILLION BUILD-OUT STRATEGY:

WMATA Metrorail extensions, capacity and service enhancements for Virginia Railway Express (VRE) and new light rail transit (LRT) are among the numerous projects proposed by the [Northern Virginia Transportation Authority](#) (NVTA) in a TransAction Plan Update adopted Oct. 12.

EXTENDED FOREIGN USE AND DEVELOPMENT OF RAILWAY FACILITIES

From the successful construction of railway projects, the economies of many foreign countries have improved. Their more popular systems need to be studied and copied to benefit the Americans.

- **Examples are the Doha to Qatar railway projects:** Doha Metro is part of a larger railway network, which consists of five modern and flexible railway systems integrated across the Persian Gulf. The larger network includes the development of passenger and freight rail transport systems, along with fast rail links to the international airport based on the Gulf Cooperation Council (GCC) feasibility study.

Currently in the planning stage, the GCC network will connect six member states, namely Oman, UAE, Qatar, Saudi Arabia, Kuwait and Bahrain, with a 1,940km rail network.

- Two major projects in India which are Hyderabad Metro and Mumbai to Ahmedabad fast train project which will reduce much of the travel time.
- In London, England, Victoria Line underground project, which carries more than 200 Million passengers each year. The author started his career working on the Victoria Line tunnel driving.

A 15 dollars program to extend the subway was completed earlier this year.

- The famous Channel Tunnel Rail Link (also known as HS-1) between UK and France is a very well managed project.
- **VIA Rail Canada** set ridership records over the Canadian Thanksgiving weekend. From Oct. 5 to 10, 2017, 193,900 passengers used VIA's four main services—Cross-Canada, Quebec-Windsor, the Montréal-Halifax *Ocean* and the Toronto-Vancouver *Canadian*—for an average 20.8% increase over the same period in 2016, excluding the *Ocean*, which rose 5%.

- **Luxembourg plans tram extensions:** Two extensions, which are to be completed by 2021, are planned. A 4.9km line from Luxemburg central station to Cloche d'Or with seven stops, and a 3.9km line from Luxexpo via Héienhaff to Findel Airport.
- **Indian Railways to build fuel-cell battery locomotive:** INDIAN Railways (IR) plans to build a hydrogen fuel cell and battery powered 300kW broad-gauge locomotive, and Diesel Locomotive Works, Varanasi has invited tenders by November 22 for components for the project.

TRAINING PROGRAMS FOR ENGINEERS: A knowledge of strength of materials, structural mechanics, specifications of fundamental codes such as AISI, ACI, ASTM, IBC, AAHTO and AREMA are required.

Comparisons of geometry of the types of bridges, methods of analysis such as equilibrium and compatibility equations for determinate and indeterminate structures, stress and strain relations, boundary conditions will be required.

Compulsory training programs on technical and managerial aspects are usually arranged by railway agencies, FRA or the state DOTs.

In addition, AREMA inspection manual for field methods of evaluating condition of railway infrastructure and bridges.

Technical decisions for selection of following need to be made as part of engineering duties:

- **Repair**
- **Retrofits:** Usually replacing conventional bearings with seismic isolation bearings or for minimizing vibrations.
- **Replacements:** Examples are over one hundred years old bridges, which have withstood the demands of time and survived corrosion, fatigue and seismic events. Amtrak has carried out replacement designs for very long Susquehanna River Bridge in Maryland and those over Connecticut River and Niantic River in CT. These bridges require very large funding and are due to start.



AMTRAK INITIATIVE FOR FAST TRAINS IN THE NORTHEAST

EXPERIENCE GAINED IN RAILWAY ENGINEERING BY RAILWAY AGENCIES: Reasons for past failures have been studied and avoided by leading railway organizations such as FRA, AREMA. Computer software development, fast computers, internet and websites and more effective communication system have helped in planning, design, construction, maintenance and operation. It is foreseen that new railway technology and with US funding exceeding 800 billion dollars, there will be tremendous advantages to the public in traveling with comfort and saving travel time and improvement in economy.

ADVANCEMENT IN I.T.: As we move towards an integrated travel system — across cities, countries, continents and, eventually, globally —

rail operators need to build platforms (both physical, such as hubs, connections, hardware for example, as well as digital hubs, including information systems, data management processes, etc.) that will provide the very best in mobility.

Further Preventive Measures for Bridge Safety:

- A. Providing space for bearing inspection chambers.
- B. Study of failure mechanism of different structural systems.
- C. Maintaining quality control and personnel safety during construction.
- D. For old bridges codes for rehabilitation of mixed old and new structural systems should be developed to enhance life and prevent early collapse.
- E. New techniques of repair and rehabilitation of substructure need to be developed and incorporated in the codes.
- F. Greater vendor and construction engineer participation in revising and developing design codes for countermeasures be encouraged.

1. CHECKS FOR DEFLECTION, SHEAR FORCES AND BENDING MOMENTS; SELECTION CRITERIA OF BRIDGE TYPES

A. Deflection Checks: Maximum permissible live load deflection = $L/640$ for railway bridges compared to $L/375$ for highway bridges

For simply supported spans recommended by AREMA Code, computed deflection under central point load = $P(L^3)/48EI$

First approximation based on sum of alternate loads of 4 axle load of 400 kips. Safe value of I is based on permissible deflection $L/640$; $I = P(L^3) \times 640/48EL$

I for the section chosen should be adequate under all load combinations. Dead load deflection is not considered since equivalent camber is provided during the fabrication of girder.

Second check based on actual 4 loads at 5,6,5 ft spacing at center of span

$$\text{Max. L.L. Defl.} = Pa (3L^2-4a^2)/24EI + Pb (3L^2-4b^2)/24EI \leq L/640$$

A. Maximum permissible shear stress = $0.4 F_y$; (F_y for steel is either 50Wksi or 70W ksi)

Dead load includes wt. of girder + wt. of rail + wt. of ballast + wt. of ties

1. Vertical shear force for dead loads and live load = V

$$\text{Shear stress } q = V/(d.t_w)$$

$(d.t_w)$ for the I girder should be adequate for all load combinations.

2. Shear stress due to torsion from lateral forces.

Lateral forces include wind + earthquake

Dead load includes wt. of girder + wt. of rail + wt. of ballast + wt. of ties

Standard torsion equation due to eccentric axle load from center line of girder

Using standard torsion equation,

$$t_u / r = G \cdot \theta / L = T / J$$

where t_u = shear stress, $G = E/2$; θ = Angle of twist; L = span

J = polar moment of inertia, T = torsional moment;

Total shear stress due to shear force V and torsional moment. St. Venna introduced torsional resistance for round cross sections. Torsion may cause warping.

Shear stress becomes high as both vertical shear and torsional shear stress gets added but can be resisted by the web and additional and longitudinal web stiffeners.

Shear stress t_{warp} from lateral wind acting on girder web (or centrifugal force generated for the curved alignment).

Total shear stress = $(q + t_u + t_{warp}) \leq 0.4 F_y$

Usually for thin webs, total shear stress will govern compared to deflection or bending. Longitudinal stiffener and vertical web stiffeners need to be provided.

C. Maximum permissible bending stress with factor of safety = 0.65 F_y ; Computed max. bending moment under central point load $P = (PL)/4$

Computed max. bending moment under uniformly distributed load, $w = (wL^2)/8$; Where w = sum of u.d.l. (for wt. of girder + wt. of rail + wt. of ballast + wt. of ties)

Using standard bending equation,

$f/y = E/R = M/I$; $M = EI/R$ or in differential equation format

$M = EI \cdot d^2y/dx^2$ in terms of beam curvature.

Standard stress equation, $f = M.y/I = M.S$ where $S = I/y$;

External bending stress $f \leq MS$

I for the section chosen should be adequate for all load combinations based on Wind, Earthquake and Braking Forces Etc.

B.M. due to alternate live load can be calculated by first principles.

B.M.s for alternate 4-x 100 kips axle loads.

4 Traveling axle loads spaced at 5,6,5 ft. acting at midspan:

For Connecticut River Bridge, Max. L = 180 ft., L/2 = 90 ft.

For symmetry about center line, a = 82 ft, b = 87 ft. P = 100 kips

$$M_{\max} = P \cdot a + P \cdot b$$

(An analysis table for max. shear forces and bending moments is available for Cooper E80 movable loads based on span lengths in AREMA)

Additional B.M. due to braking forces acting at 8 ft. need to be added as required by AREMA.

Cover plates on top and bottom flanges need to be added to make section compact resulting in greater head room than minimum 23 ft.

Girder moment of inertia I value can be increased significantly by providing composite action with deck slab by using shear connectors. Above hand calculations can be used to check computer results (from STAAD-Pro).

- BRT (BUS-RAIL TRANSIT) SYSTEM needs to be promoted.
- Amtrak Train “the sunset limited” from New Orleans to Los Angeles is just fantastic.
- America by Rail is the Best Way to See America!
- Current financing requirement for U.S. Transportation exceeds one trillion dollars. But we are slowly getting there.
- As population increases in the cities, the greater will be the demand of passenger train travel. While freight trains are a must, even in sparsely populated areas.