STRUCTURAL DESIGN

Joseph T Wunderlich PhD

ARCHITECTS complete studies in:

- Architecture Design Studios (Many)
- Architecture Theory
- Drawing, Painting, Sculpture
- Architectural and Art History (at least two courses)
- Urban Design and Landscape Architecture
- Architectural Materials & Methods
- Lighting Design (inc.luding Solar)
- Acoustical Design
- Geology
- Environmental Philosophy and Sciences
- Architectural and Environmental Standards and codes
  - Master Plans, AIA and LEED standards, Building Codes
- Communications (at least two courses)
  - (Visual Comm, Graphic Design, Web Design, Video, Cinema, etc)
- Common Electives:
  - Real Estate Development
  - Music *(Frank Lloyd Wright's school required this)*
- Some HVAC Design inc.luding Solar (in practice, consult Engineers as needed)
- Some Electrical Power (in practice, consult Engineers as needed)
- Some Water and Wastewater Design (in practice, consult Engineers as needed)
- **STRUCTURAL DESIGN** (in practice, consult Engineers as needed) . . . . →

ARCHITECTS need knowledge of many things, and for very large structures consults Engineers in fields of Mechanical(HVAC), Electrical(Power), Water & Wastewater, and Structural

- Architects need:
  1. Structural concepts covered in courses relating to Architecture
  2. Typically **#1 and #2 below**

Courses taken by **STRUCTURAL ENGINEERS:**

(1) PHYSICS

- Introduces topics covered in extreme depth in later Engineering courses
- Calculus or Algebra-Based

(2) GEOLOGY

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(3) STATICS (Sum of Forces = Zero)

(4) DYNAMICS (Sum of Forces does not = Zero, so objects are in motion)

- **(5) ANALYTICAL MECHANICS** (Advanced Dynamics for Physicists and some Engineers)

(6) STRENGTH OF MATERIALS (Material **internal** reactions to Static & Dynamic Forces)

- **(7) MATERIAL SCIENCE** (material properties from molecular level up, studied by some Engineers)

(8) STRUCTURAL ANALYSIS (Statics & Dynamics of Complex Structures)

(9) STEEL STRUCTURAL ENGINEERING

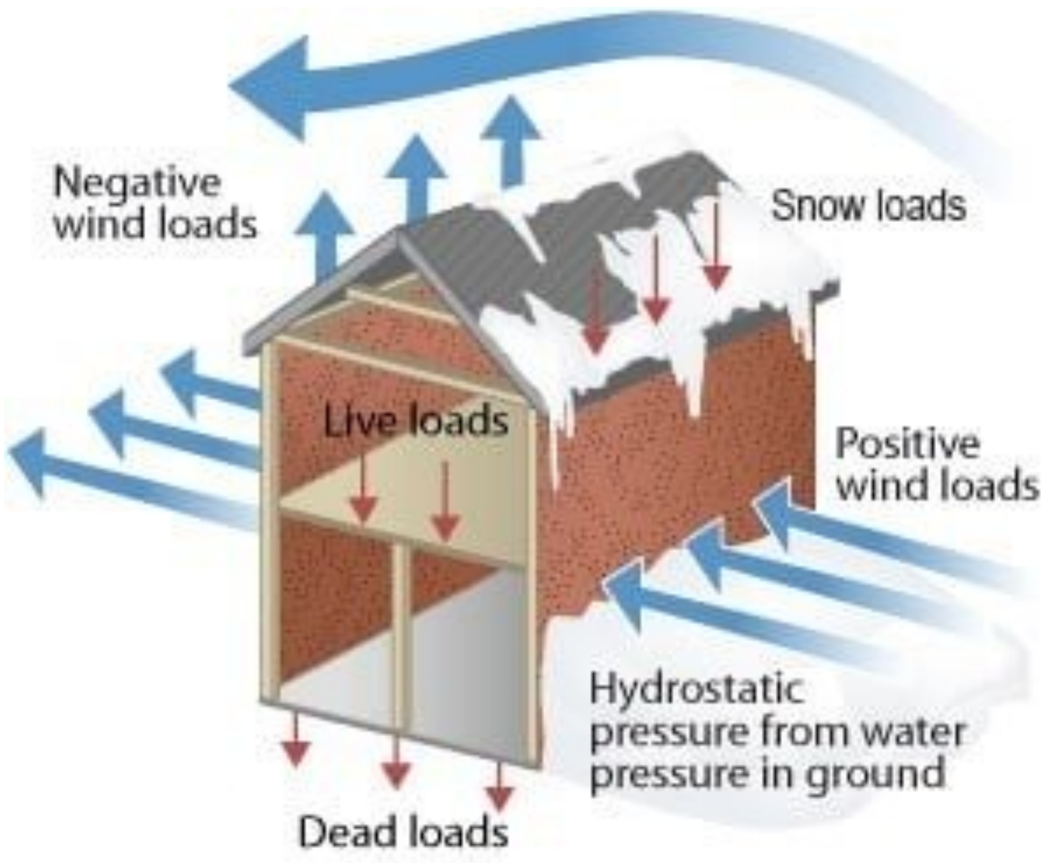
(10) REINFORCED CONCRETE STRUCTURAL ENGINEERING (A composite material)

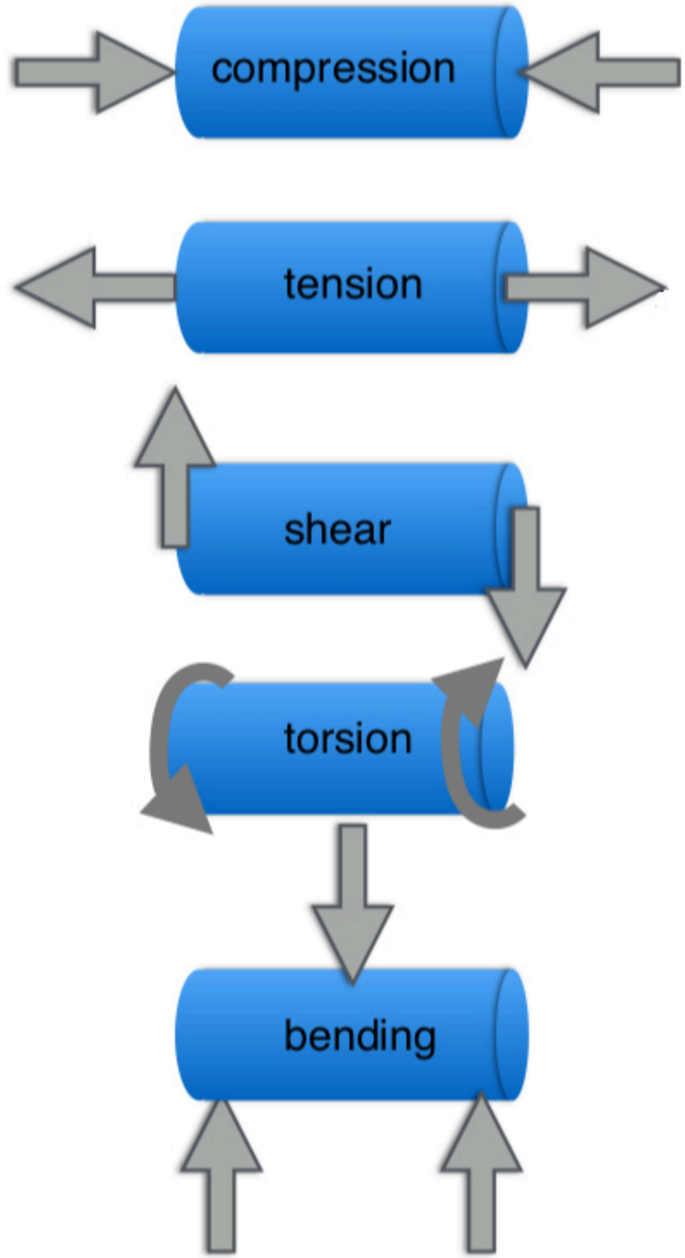
(11) WOOD DESIGN STRUCTURAL ENGINEERING

NOTE: Dr W took all 11 courses

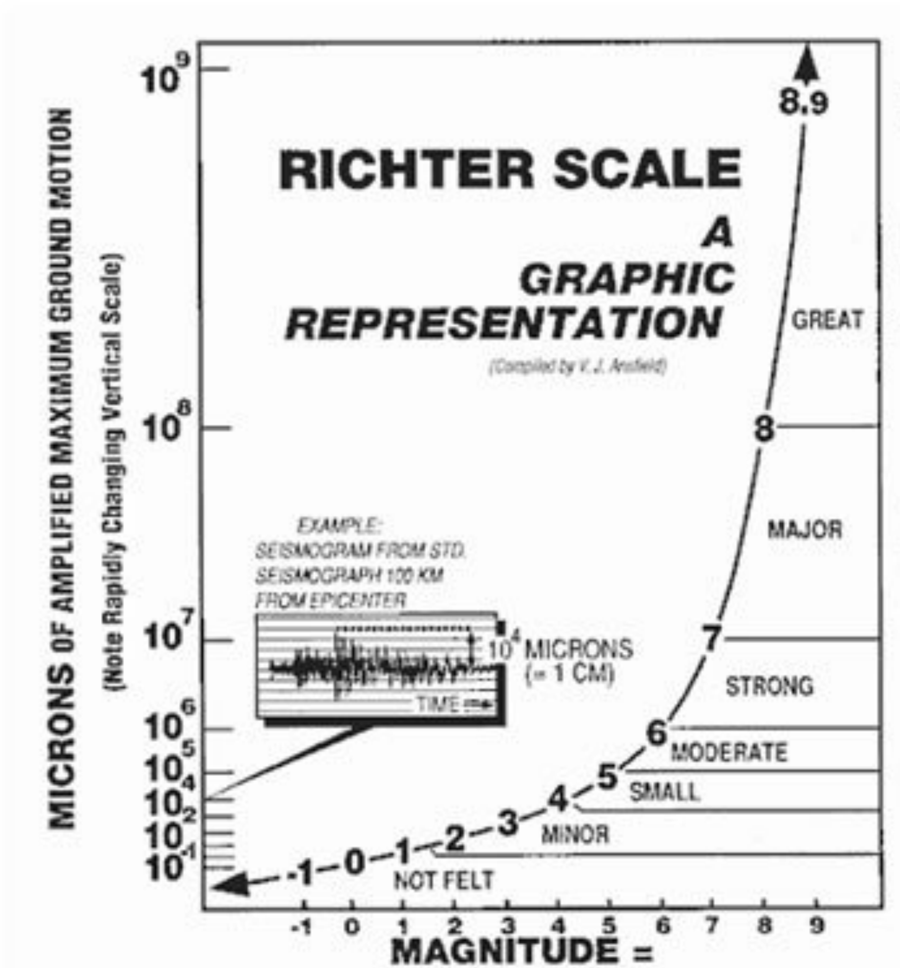
FORCES

(Loads and Material Reactions)





LOADS (Seismic)



Richter Scale of Earthquake Energy:

Each level is <u>10 time stronger</u> than the previous level

	Description	Occurrence	In Population	Movement
1	Small	Daily	Every minute	Small
2	Small	Daily	Every hour	Small
3	Small	Daily	Every day	Small
4	Small	Daily	Every week	Moderate sudden
5	Moderate	Monthly	Every 10 years	Strong Sudden
6	Moderate	Monthly	Every 30 years	Strong Sudden
7	Major	Monthly	Every 50 years	Severe Sudden
8	Great	Yearly	Every 100 years	Very Severe
9	Great	Yearly	Every 300 years	Very Severe
10	Super	Rarely	Every 1.000 years	Extreme

source

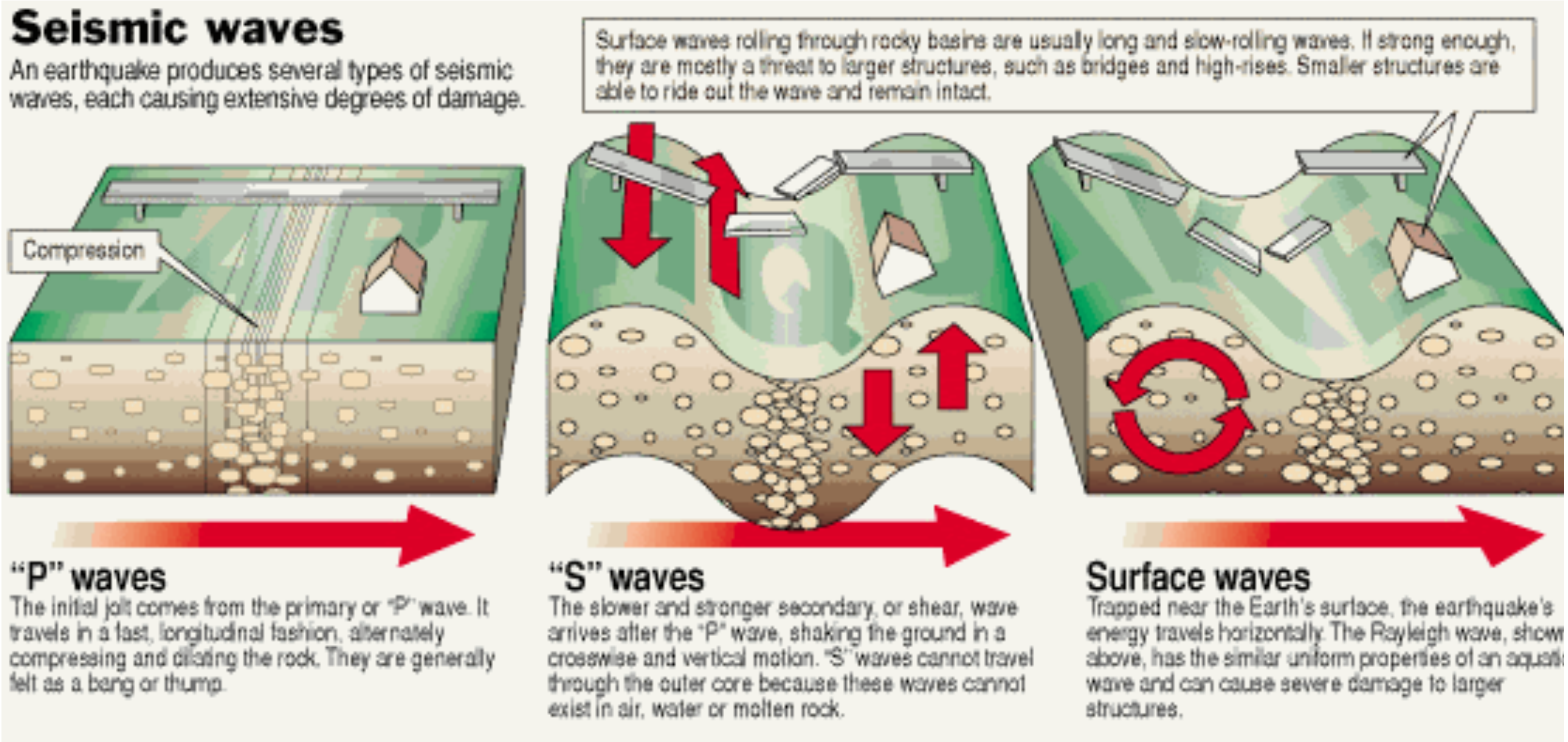
LOADS (Seismic)

Richter Magnitude	Feels like KG of TNT	Extra Information
0-1	0.6-20 kilograms of dynamite	We can not feel these
2	600 kilograms of dynamite	Smallest Quake people can normally feel
3	20,000 kilograms of dynamite	People near the epicenter feel this quake
4	60,000 kilograms of dynamite	This will cause damage around the epicenter. It is the same as a small fission bomb
5	20,000,000 kilograms of dynamite	Damage done to weak buildings in the area of the epicenter
6	60,000,000 kilograms of dynamite	Can cause great damage around the epicenter
7	20 bilion kilograms of dynamite	Creates enough energy to heat New York city for one year. Can be detected all over the world. Causes serious damage
8	60 bilion kilograms of dynamite	Causes death and major destruction. Destroyed San Francisco in 1906
9	20 trillion kilograms of dynamite	Rare, but would causes unbelievable damage!

source

LOADS (Seismic)

- ***"P Waves (Primary Waves)** are the first waves to be released. They compress and expand the ground. **S Waves (Secondary Waves)** are the second waves released. They shake the earth up, down , and side to side. **Surface Waves** are the waves that hit the surface. They are slower than P and S waves but make the most severe damage. Surface waves shake building side to side"*



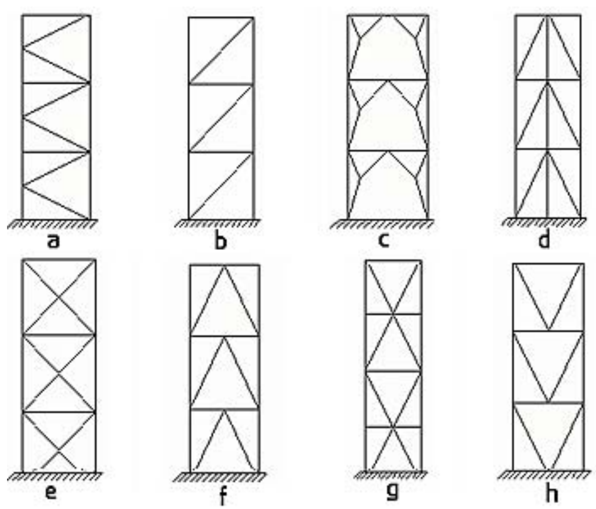
Designing for Seismic LATERAL LOAD

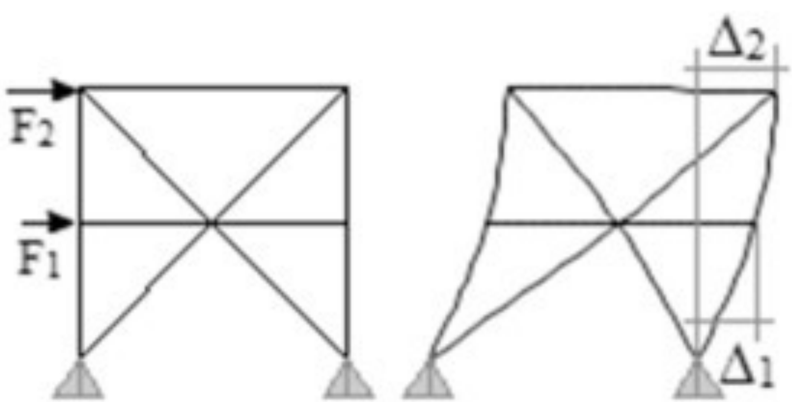
- Method 1 **SHEAR WALL** (VIDEO)

Designing for Seismic LATERAL LOAD

Method 2 **BRACED-FRAME**

(with Diagonal braces)

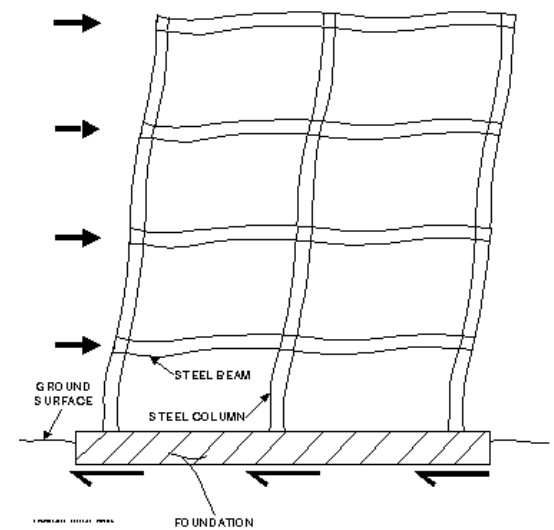




Method 3 **MOMENT CONNECTION**

(Stiff FIXED MOMENT-resisting joints)

<u>A MOMENT is a TORQUE</u>



Designing for Seismic LATERAL LOAD

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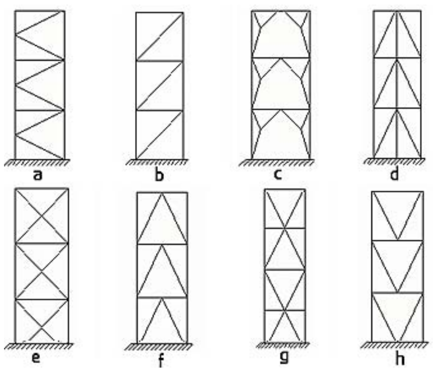

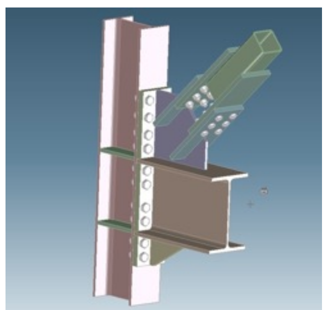

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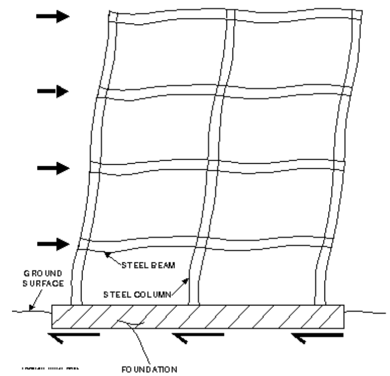

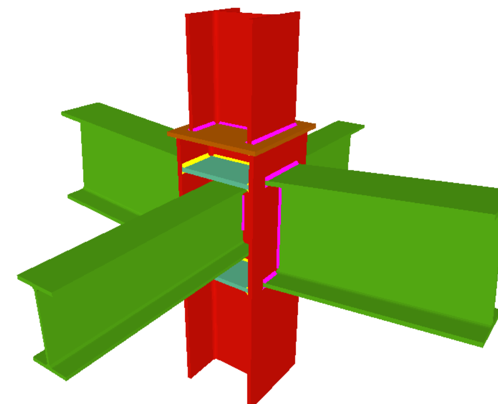

Designing for Seismic LATERAL LOAD

Method 2 **BRACED-FRAME**

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Method 3 **MOMENT CONNECTION**

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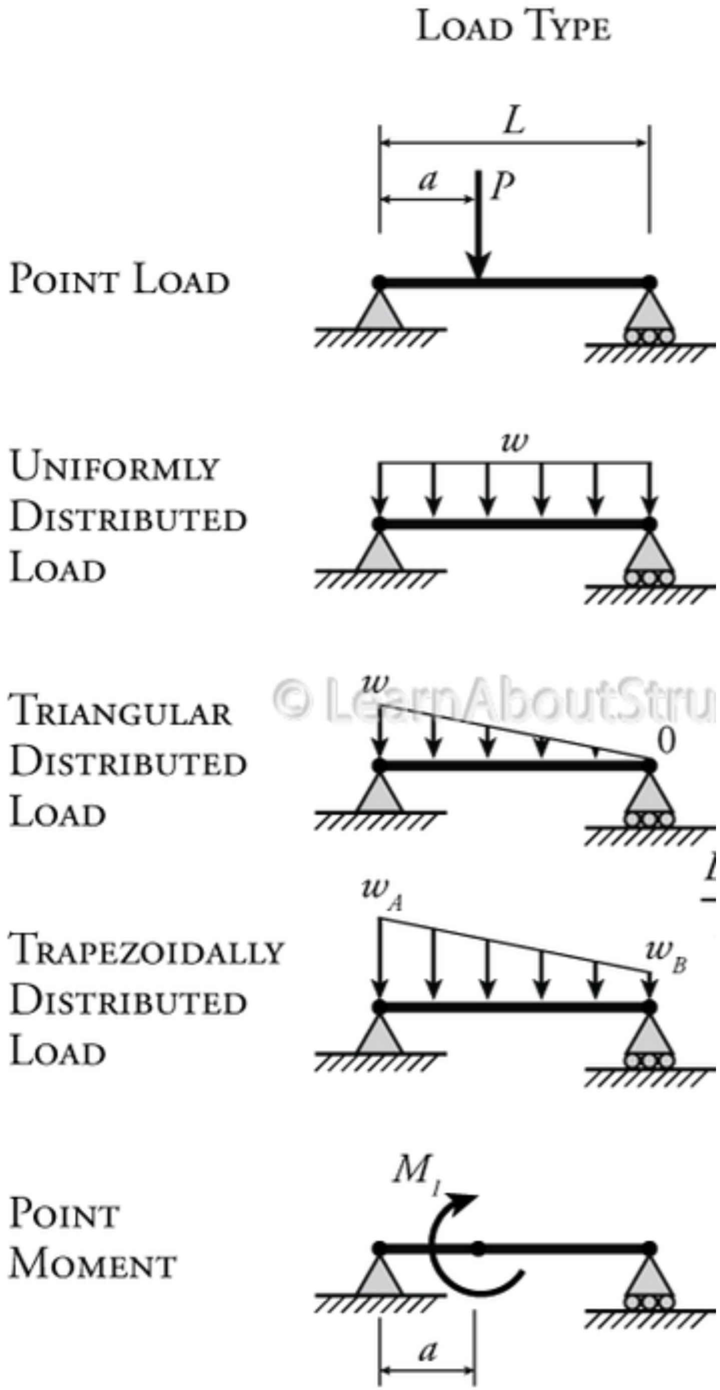
LOADS



MOMENT
(TORQUE)

BEAM

with a POINT LOAD, and ends that are free to rotate

- **R are reaction forces at ends**

  Shown on a <u>F</u>REE <u>B</u>ODY <u>D</u>IAGRAM **(FBD)**

- **SHEAR** *felt by beam*

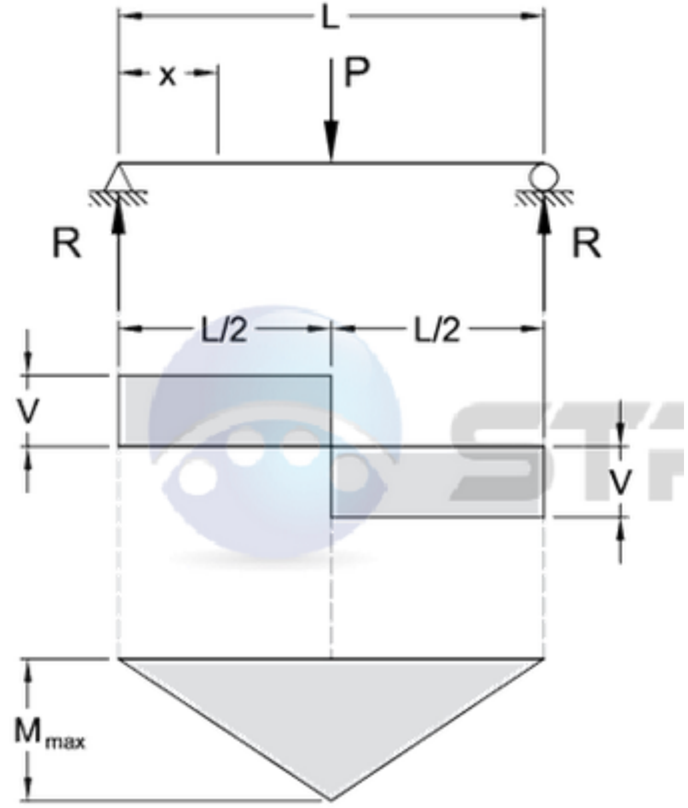
  Shown on a <u>S</u>HEAR <u>F</u>ORCE <u>D</u>IAGRAM **(SFD)**

- **MOMENT** (TORQUE)

  Shown on <u>B</u>ENDING <u>M</u>OMENT <u>D</u>IAGRAM (**BMD**)

  TORSION is the twisting of the beam

  due to the MOMENT(TORQUE)

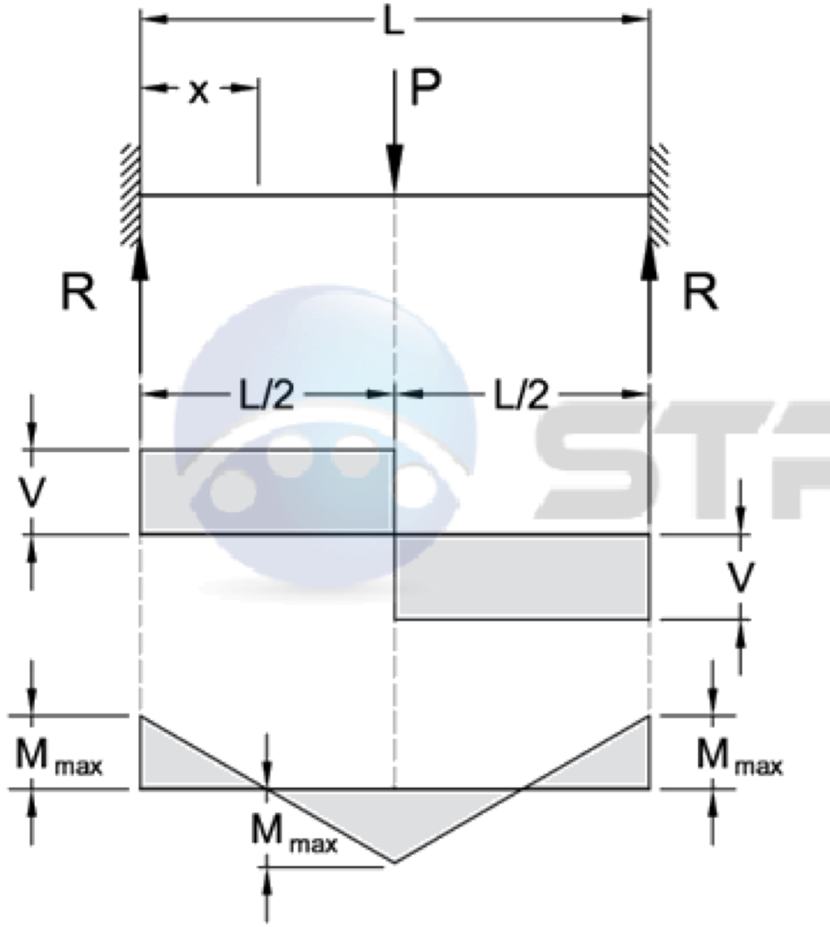


BEAM

with a POINT LOAD and ends that are FIXED (can't rotate)

- **R is reaction force at ends**

  Shown on a FREE BODY DIAGRAM **(FBD)**



- **SHEAR** *felt by beam*

  Shown on a SHEAR FORCE DIAGRAM **(SFD)**

- **MOMENT** (like TORQUE without motion)

  TORSION *felt by beam*

  Shown on BENDING MOMENT DIAGRAM (**BMD**)

BEAM

with a UNIFORM LOAD and beam-ends that are FIXED (can't rotate) and with MOMENTS applied at ends (from adjoining structure)

- **R are reaction forces at beam-ends (supports)**

  Shown on a F̲REE B̲ODY D̲IAGRAM **(FBD)**

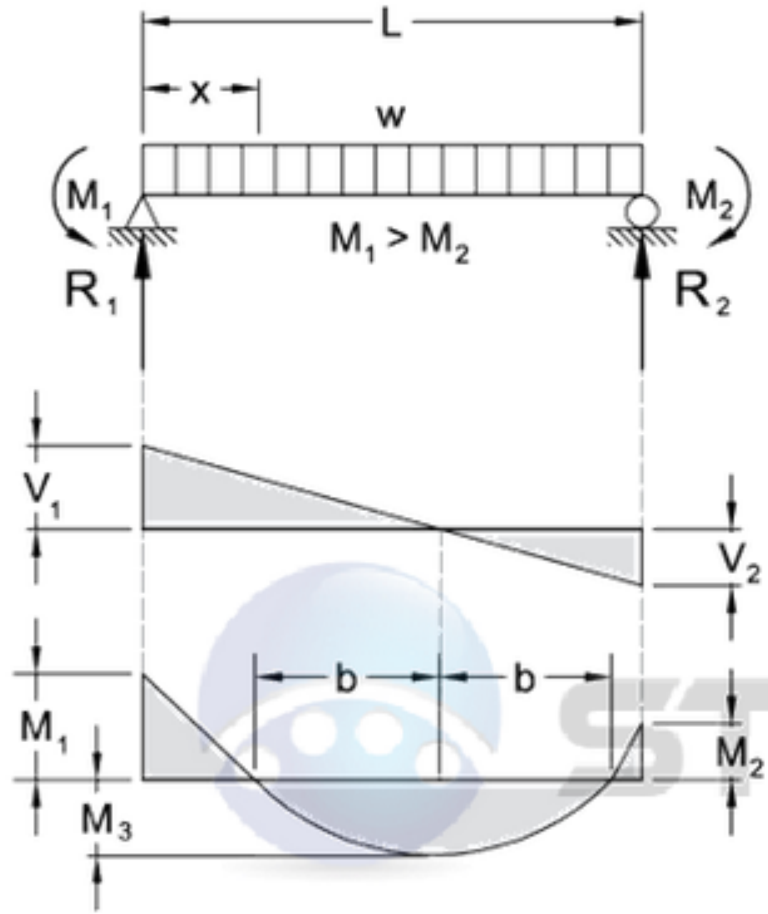
- **SHEAR** *felt by beam*

  Shown on a S̲HEAR F̲ORCE D̲IAGRAM **(SFD)**

- **MOMENT** (like TORQUE without motion)

  TORSION *felt by beam*

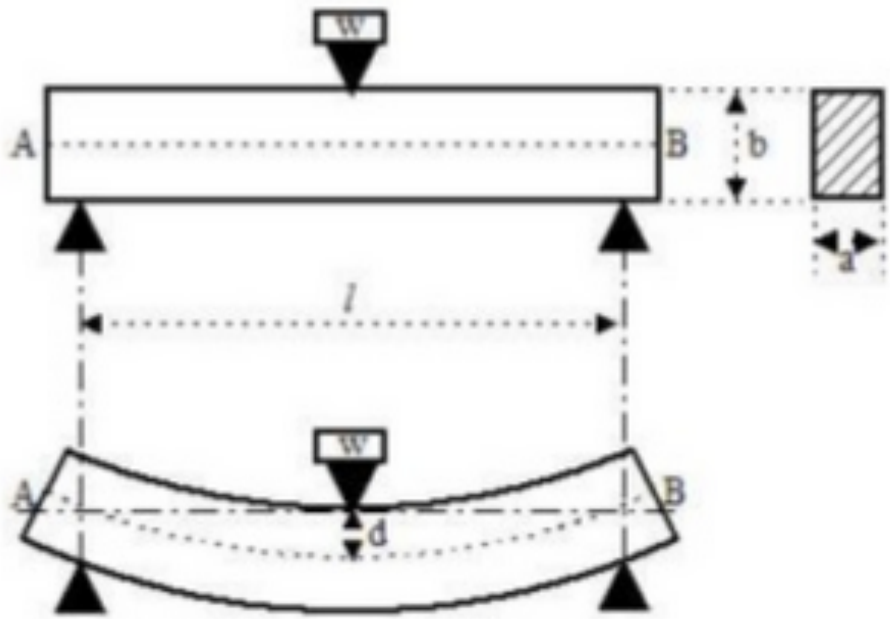
  Shown on B̲ENDING M̲OMENT D̲IAGRAM (**BMD**)



BEAM **DEFLECTION (DEFORMATION)**

with a POINT LOAD and ends that are free to rotate

Deflection is deformation from original position in y direction



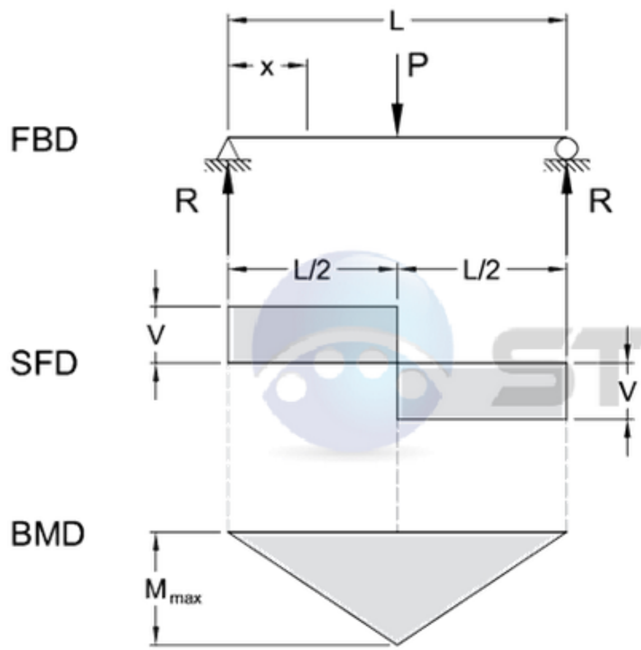
▫ BEAM

FORMULAS

with a POINT LOAD and ends that are free to rotate

E = MODULUS OF ELASTICITY and depends on the beam's matrial *(units = PSI or Pascals)*
I = **MOMENT OF INERTIA** and depends on the shape of beam's cross-section *(units = feet^4 or meters^4)*
L = Length of beam (it's SPAN) *(units = feet or meters)*
M = **MOMENT** *(units = foot-pounds or Newton-meters)*
P = **POINT LOAD** *(units = pounds or Newtons)*
R = **REACTION** FORCE *(units = pounds or Newtons)*
V = **SHEAR** FORCE *(units = pounds or Newtons)*
Δ = **DEFLECTION** (DEFORMATION) *(units = feet or meters)*

FBD = free body diagram
SFD = shear force diagram
BMD = bending moment diagram



$$R = V = \frac{P}{2}$$

$$M_{max} \text{ (at point of load)} = \frac{PL}{4}$$

$$M_x\left(x < \frac{L}{2}\right) = \frac{Px}{2}$$

$$\Delta_{max} \text{ (at point of load)} = \frac{PL^3}{48EI}$$

$$\Delta_x\left(x < \frac{L}{2}\right) = \frac{Px}{48EI}(3L^2 - 4x^2)$$

BEAM FORMULAS

with a POINT LOAD and ends that are FIXED (can't rotate)

E = MODULUS OF ELASTICITY and depends on the beam's material *(units = PSI or Pascals)*

I = **MOMENT OF INERTIA** and depends on the shape of beam's cross-section *(units = feet^4 or meters^4)*

L = Length of beam (it's SPAN) *(units = feet or meters)*

M = **MOMENT** *(units = foot-pounds or Newton-meters)*

P = **POINT LOAD** *(units = pounds or Newtons)*

R = **REACTION** FORCE *(units = pounds or Newtons)*

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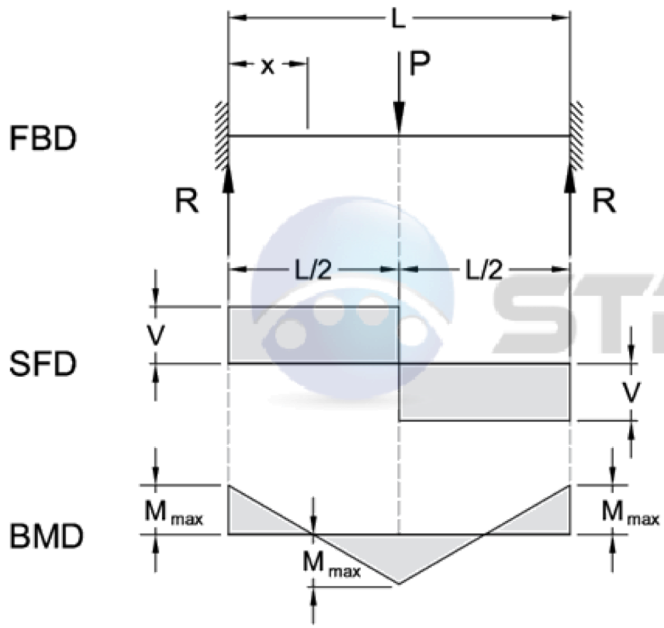

$$R = V \ldots = \frac{P}{2}$$

$$M_{max} \text{ (at centre and ends)} \ldots = \frac{PL}{8}$$

$$M_x\left(x < \frac{L}{2}\right) \ldots = \frac{P}{8}(4x - L)$$

$$\Delta_{max} \text{(at centre)} \ldots = \frac{PL^3}{192EI}$$

$$\Delta_x\left(x < \frac{L}{2}\right) \ldots = \frac{Px^2}{48EI}(3L - 4x)$$

$$x \text{ (point of contraflexure)} \ldots = \frac{L}{4}$$

BEAM

with a UNIFORM LOAD and ends that are FIXED (can't rotate)

and with MOMENTS applied at ends (from adjoining structure)

FORMULAS

E = **MODULUS OF ELASTICITY** and depends on the beam's material *(units = PSI or Pascals)*

I = **MOMENT OF INERTIA** and depends on the shape of beam's cross-section *(units = feet^4 or meters^4)*

L = Length of beam (it's SPAN) *(units = feet or meters)*

M = **MOMENT** *(units = foot-pounds or Newton-meters)*

w = **UNIFORM LOAD** *(units = pounds **per foot** or Newtons **per meter**)*

R = **REACTION** FORCE *(units = pounds or Newtons)*

V = **SHEAR** FORCE *(units = pounds or Newtons)*

Δ = **DEFLECTION** (DEFORMATION) *(units = feet or meters)*

FBD = free body diagram
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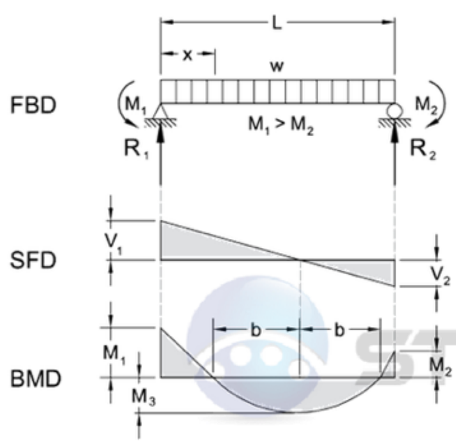

$$R_1 = V_1 \; \ldots\ldots \; = \frac{wL}{2} + \frac{M_1 - M_2}{L}$$

$$R_2 = V_2 \; \ldots\ldots \; = \frac{wL}{2} - \frac{M_1 - M_2}{L}$$

$$V_x \; \ldots\ldots \; = w\left(\frac{L}{2} - x\right) + \frac{M_1 - M_2}{L}$$

$$b \text{ (inflection points)} \; \ldots \; = \sqrt{\frac{L^2}{4} - \left(\frac{M_1 + M_2}{w}\right) + \left(\frac{M_1 + M_2}{wL}\right)^2}$$

$$M_x \; \ldots\ldots \; = \frac{wx}{2}(L - x) + \left(\frac{M_1 - M_2}{L}\right)x - M_1$$

$$M_3 \left(\text{at } x = \frac{L}{2} + \frac{M_1 - M_2}{wL}\right) \; \ldots\ldots \; = \frac{wL^2}{8} - \frac{M_1 + M_2}{2} + \frac{(M_1 - M_2)^2}{2wL^2}$$

$$\Delta_x \; \ldots\ldots \; = \frac{wx}{48EI}\left(x^3 - \left(2L + \frac{4M_1}{wL} - \frac{4M_2}{wL}\right)x^2 + \frac{12M_1}{w} + L^3 + \frac{8M_1L}{w} - \frac{4M_2L}{w}\right)$$

FORMULAS

- **BEAM**

  with a <u>UNIFORM</u> LOAD and ends that are FIXED (can't rotate)

  and with <u>MOMENTS applied at ends</u> (from adjoining structure)

E = <u>MODULUS OF ELASTICITY</u> and depends on the beam's material *(units = PSI or Pascals)*

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w = **<u>UNIFORM</u> LOAD** *(units = pounds **per foot** or Newtons **per meter**)*

R = **REACTION** FORCE *(units = pounds or Newtons)*

V = **SHEAR** FORCE *(units = pounds or Newtons)*

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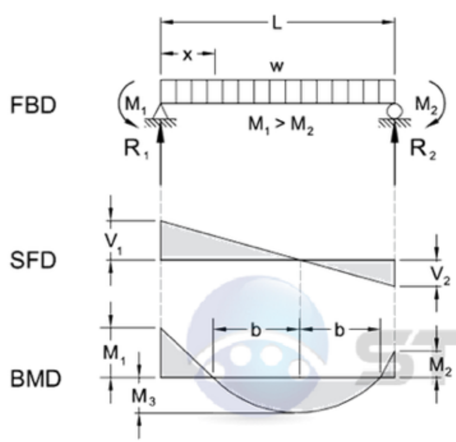


$$R_1 = V_1 \dots\dots = \frac{wL}{2} + \frac{M_1 - M_2}{L}$$

$$R_2 = V_2 \dots\dots = \frac{wL}{2} - \frac{M_1 - M_2}{L}$$

$$V_x \dots\dots = w\left(\frac{L}{2} - x\right) + \frac{M_1 - M_2}{L}$$

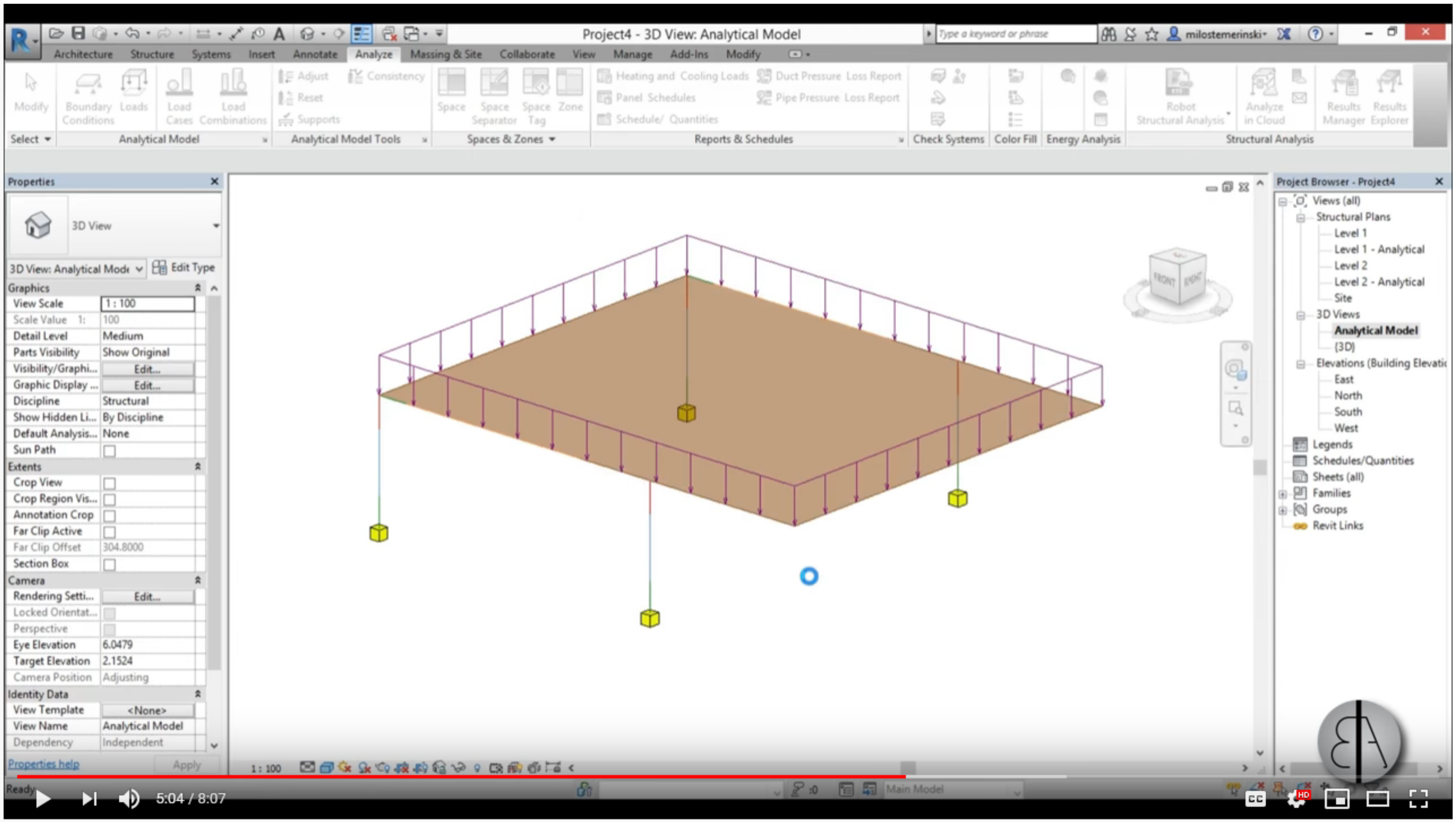
$$b \text{ (inflection points)} \dots = \sqrt{\frac{L^2}{4} - \left(\frac{M_1 + M_2}{w}\right) + \left(\frac{M_1 + M_2}{wL}\right)^2}$$

$$M_x \dots\dots = \frac{wx}{2}(L - x) + \left(\frac{M_1 - M_2}{L}\right)x - M_1$$

$$M_3 \left(\text{at } x = \frac{L}{2} + \frac{M_1 - M_2}{wL}\right) \dots\dots = \frac{wL^2}{8} - \frac{M_1 + M_2}{2} + \frac{(M_1 - M_2)^2}{2wL^2}$$

$$\Delta_x \dots\dots = \frac{wx}{48EI}\left(x^3 - \left(2L + \frac{4M_1}{wL} - \frac{4M_2}{wL}\right)x^2 + \frac{12M_1}{w} + L^3 + \frac{8M_1 L}{w} - \frac{4M_2 L}{w}\right)$$

[Revit STRUCTURAL](#) video



Structural Analysis in Revit Tutorial

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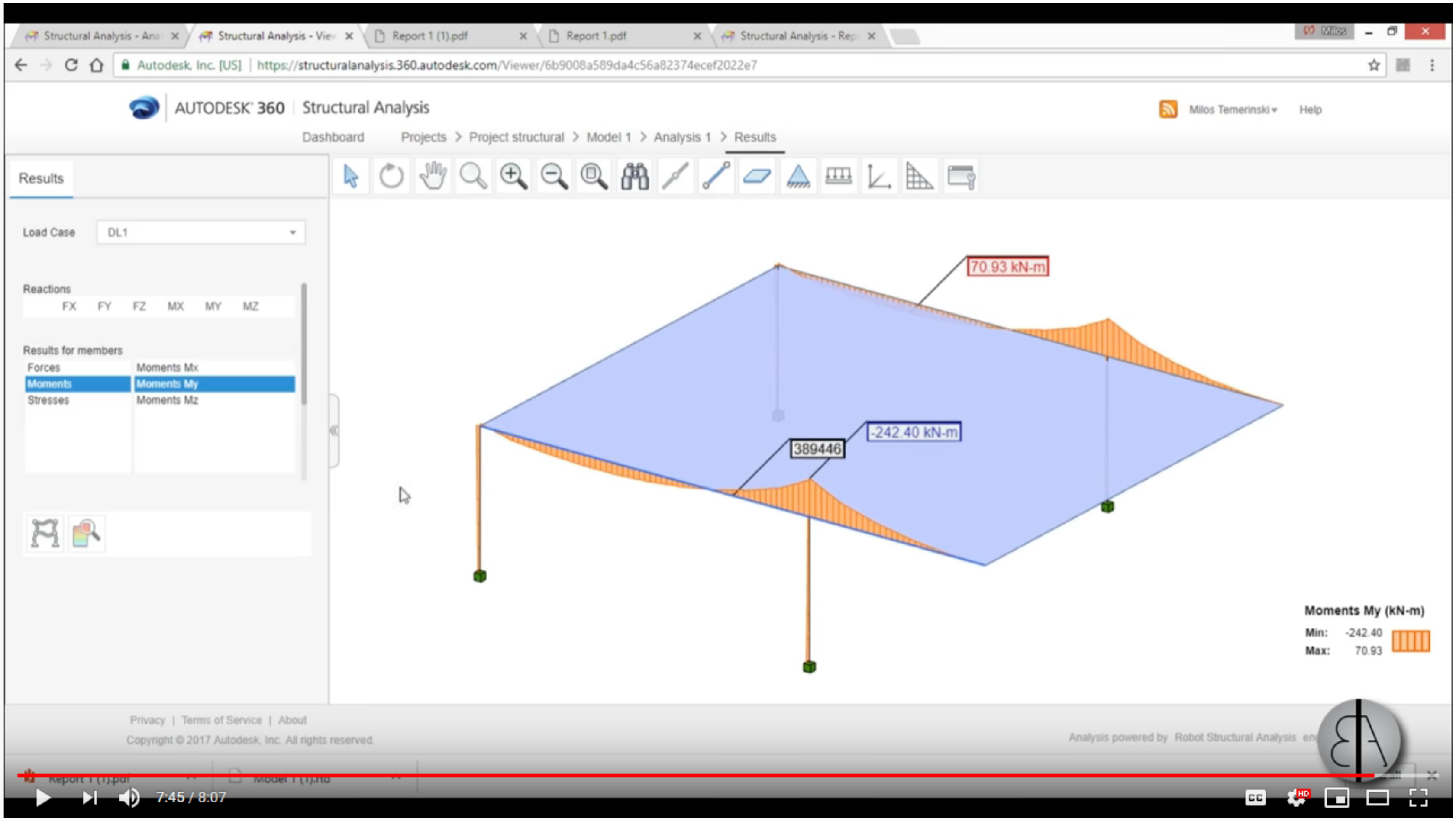
Revit STRUCTURAL video



Structural Analysis in Revit Tutorial

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- **BUILDING CODE** is **enforced** by government **jurisdictions:**
- International Building Code (**IBC**) is updated every 3 years
  - IBC Minimum Design Loads for Snow, Wind, Seismic, and Rain are taken from ASCE 7-16
  - The building code sets minimums to be enforced
- Can just use tables to size beams for small structures
- **STRUCTURAL ENGINEER** is needed for **complex structures**
  - Uses **MATERIAL CODES**
  - Creates structural working drawings and specifications

DESIGN beam using tables

- Step 1
  - **BUILDING CODE** requirements
  - **MINIMIZE DEFLECTION**

MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS	
Use	**Live Load**
Balconies (exterior)	60
Decks	40
Fire escapes	40
Garages (passenger cars only)	50
Attics (no storage with roof slope no steeper than 3 in 12)	10
Attics (limited attic storage)	20
Rooms (except sleeping rooms)	40
Sleeping Rooms	30
Stairs	40
ALLOWABLE DEFLECTION OF STRUCTURAL MEMBERS	
Structural Member	**Allowable Deflection**
Rafters with slope > 3/12 and no ceiling attached	L/180
Interior walls and partitions	H/180
Floors and plastered ceilings	L/360
All other structural members	L/240
Notes: L = span length, H = vertical span	

DESIGN beam using tables

- **Step 2**
  - Use a table applicable to the material you've chosen
  - This one is for **Wood**, and is specific to a L/360 maximum defection, and a 40 pound live load
  - And the designer is looking for a **FLOOR JOIST** that will span 15 feet, and where joists will be spaced 16 inc.hes apart
  - So a 15'-3" long 2"x10" will work, or a 15'-10" long 2"x12"
  - We will discuss Modulus of Elasticity and Bending Design Value (Fb) in later lectures

FLOOR JOISTS WITH L/360 DEFLECTION LIMITS

DESIGN CRITERIA:
Deflection - For 40 PSF live load.
Limited to span in inches divided by 360.
Strength - Live load of 40 psf plus dead load of 10 psf determines the required bending design value.

Joist Size (in.)	Spacing (in.)	Modulus of Elasticity, E, in 1,000,000 psi								
		0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
2x6	12.0	8-6	8-10	9-2	9-6	9-9	10-0	10-3	10-6	10-9
	16.0	7-9	8-0	8-4	8-7	8-10	9-1	9-4	9-6	9-9
	19.2	7-3	7-7	7-10	8-1	8-4	8-7	8-9	9-0	9-2
	24.0	6-9	7-0	7-3	7-6	7-9	7-11	8-2	8-4	8-6
2x8	12.0	11-3	11-8	12-1	12-6	12-10	13-2	13-6	13-10	14-2
	16.0	10-2	10-7	11-0	11-4	11-8	12-0	12-3	12-7	12-10
	19.2	9-7	10-0	10-4	10-8	11-0	11-3	11-7	11-10	12-1
	24.0	8-11	9-3	9-7	9-11	10-2	10-6	10-9	11-0	11-3
2x10	12.0	14-4	14-11	15-5	15-11	16-5	16-10	17-3	17-8	18-0
	16.0	13-0	13-6	14-0	14-6	14-11	15-3	15-8	16-0	16-5
	19.2	12-3	12-9	13-2	13-7	14-0	14-5	14-9	15-1	15-5
	24.0	11-4	11-10	12-3	12-8	13-0	13-4	13-8	14-0	14-4
2x12	12.0	17-5	18-1	18-9	19-4	19-11	20-6	21-0	21-6	21-11
	16.0	15-10	16-5	17-0	17-7	18-1	18-7	19-1	19-6	19-11
	19.2	14-11	15-6	16-0	16-7	17-0	17-6	17-11	18-4	18-9
	24.0	13-10	14-4	14-11	15-4	15-10	16-3	16-8	17-0	17-5
F_b	12.0	718	777	833	888	941	993	1043	1092	1140
F_b	16.0	790	855	917	977	1036	1093	1148	1202	1255
F_b	19.2	840	909	975	1039	1101	1161	1220	1277	1333
F_b	24.0	905	979	1050	1119	1186	1251	1314	1376	1436

Note: The required bending design value, F_b, in pounds per square inch is shown at the bottom of each table and is applicable to all lumber sizes shown. Spans are shown in feet - inches and are limited to 26' and less. Check sourcesof supply for availability of lumber in lengths greater than 20'.

DESIGN beam for complex structure using MATERIAL CODES

ALUMINUM

- ADM 1-00, ***"Aluminum Design Manual: Part 1-A Aluminum Structures, Allowable Stress Design "***
  - The IBC designates the ADM as the code required Aluminum Design Manual.

CONCRETE

- ACI 318-xx, ***"Building Code Requirements for Structural Concrete and Commentary"***
  - The main concrete code in use.

MASONRY

- ACI 530, ***"Building Code Requirements for Masonry Structures"***
- ASCE 5/ TMS 402
- MSJC Code : Building Code Requirements for Masonry Structures
- ACI 530.1/ ASCE 6/ TMS 602

STEEL

- AISC 341, ***"Seismic Provisions for Structural Steel Buildings"***
  - Seismic design criteria for structural steel.
- AISC 360, ***"Specification for Structural Steel Buildings (13th Edition)"***
  - Design criteria for all elements of a structure (e.g. beams, columns, bolts, welds, etc.)

WELDING

- AWS D1.1-xx, ***"Structural Welding Code, Steel"***

WOOD

- AF&PA NDS-xx, ***"National Design Specification (NDS) for Wood Construction with 20xx Supplement"***

FACTOR OF SAFETY built into Material codes

- A FACTOR OF SAFETY is built into Material Code to compensate for varying qualities of materials when manufactured and installed

- Materials have different predicted structural strength certainties based on statistical destructive testing of materials

- **STEEL is the most predictable** because of the **highly controlled quality** during manufacturing
  - **REINFORCED CONCRETE is less predictable** than steel because of variations in size of aggregate (rocks) despite what has been specified, or improper mixing (e.g, **too much WATER** will greatly reduce strength), or improper **CURING** (e.g., how long you keep water and heat within it), or not enough **VIBRATING** (to get out air pockets)
  - **WOOD is less predictable than steel** because of variations in dryness, or inaccurate grading of material (e.g., Structural Grade #1, or #2, or "Common grade")

Structural Building Material choices

- We will have entire lectures on **WOOD, MASONRY, REINFORCED-CONCRETE**, and **STEEL**
  - And other building materials

- However, start comparing materials **HERE**

- A few Wunderlich projects will be **CASE STUDIES:**

Wunderlich Pennsylvania Residence (2000's)

Wunderlich Pennsylvania Residence (2000's) **WOOD**

Wunderlich Pennsylvania Residence (2000's)

Masonry

JT Wunderlich 1984,85 Project Manager / Designer

STEEL FRAME

*"West Lake Oaks" (**13 building Hi-Tech office park**),*

Doerring Development, Austin TX

JT Wunderlich 1985,86
Director of Projects / Designer
JDC Development, La Jolla, CA

STEEL and REINFORCED CONCRETE

JT Wunderlich 1985,86
Director of Projects / Designer
JDC Development, La Jolla, CA

STEEL and REINFORCED CONCRETE

Structural Failure Analysis

WOOD

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and **lived in San Francisco very close to this structure**

Structural Failure Analysis

WOOD

- 1989 San Francisco Bay Area Earthquake
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Structural Failure Analysis

WOOD

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

The critical failure in this design was that the first floor, being made of parking garages, had less SHEAR WALL resistance to lateral seismic loads

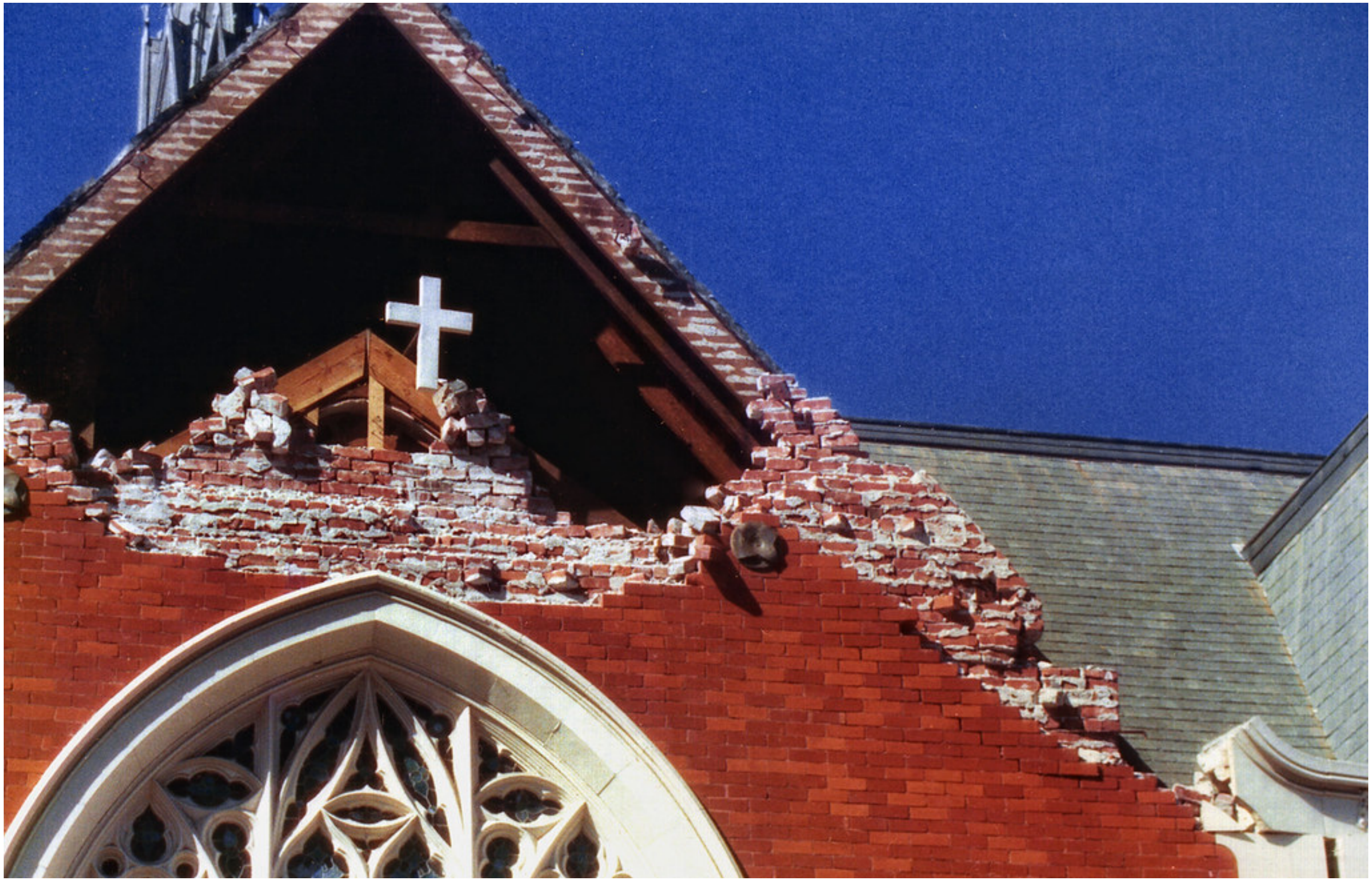
- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and **lived in San Francisco very close to this structure**

Structural Failure Analysis

MASONRY

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

The critical failure in this design was that UNREINFORCED MASONRY should simply not be used in earthquake prone areas

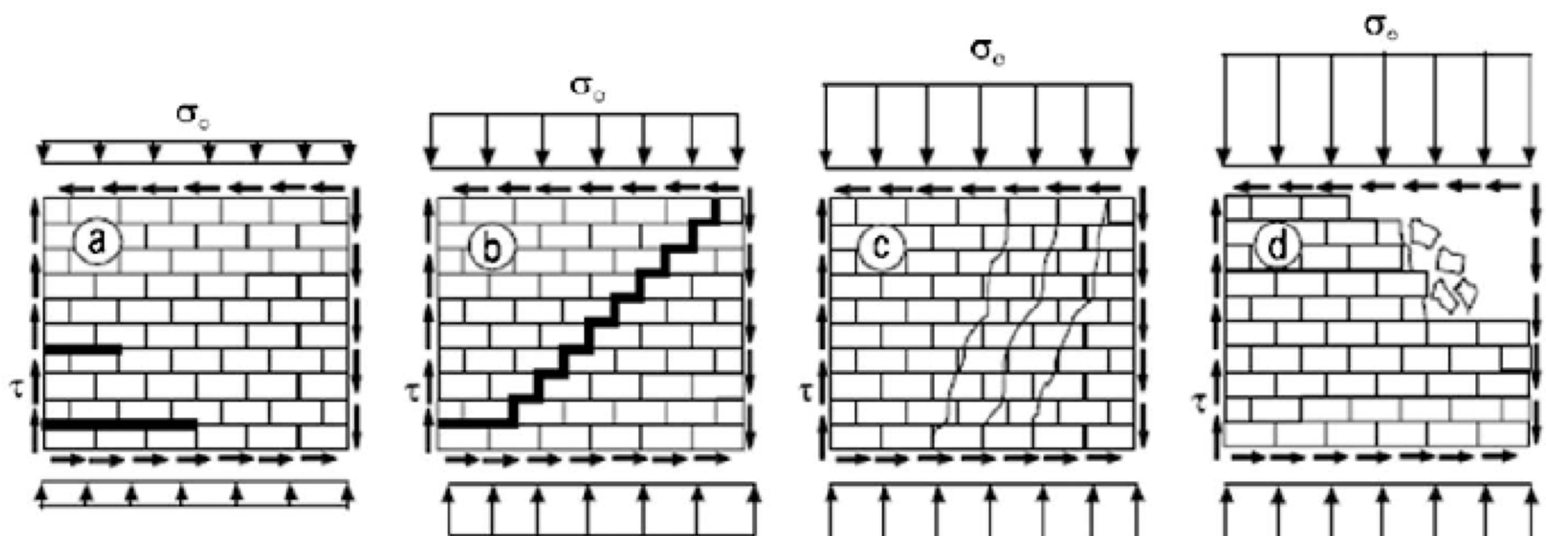


- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and **his wife worked in San Francisco near brick facades like on this structure**

Structural Failure Analysis

MASONRY

- 1989 San Francisco Bay Area Earthquake
  - “Loma Prieta Earthquake,” Magnitude 6.9



a) Bond tensile failure

b) Bond shear failure in the bed joints

c) Tension failure of the blocks

d) Compression failure of masonry

- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and **his wife worked in San Francisco near brick facades**

Structural Failure Analysis

REINFORCED CONCRETE

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and would **often drive on Nimitz freeway to meetings** in Oakland

Structural Failure Analysis

REINFORCED CONCRETE

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

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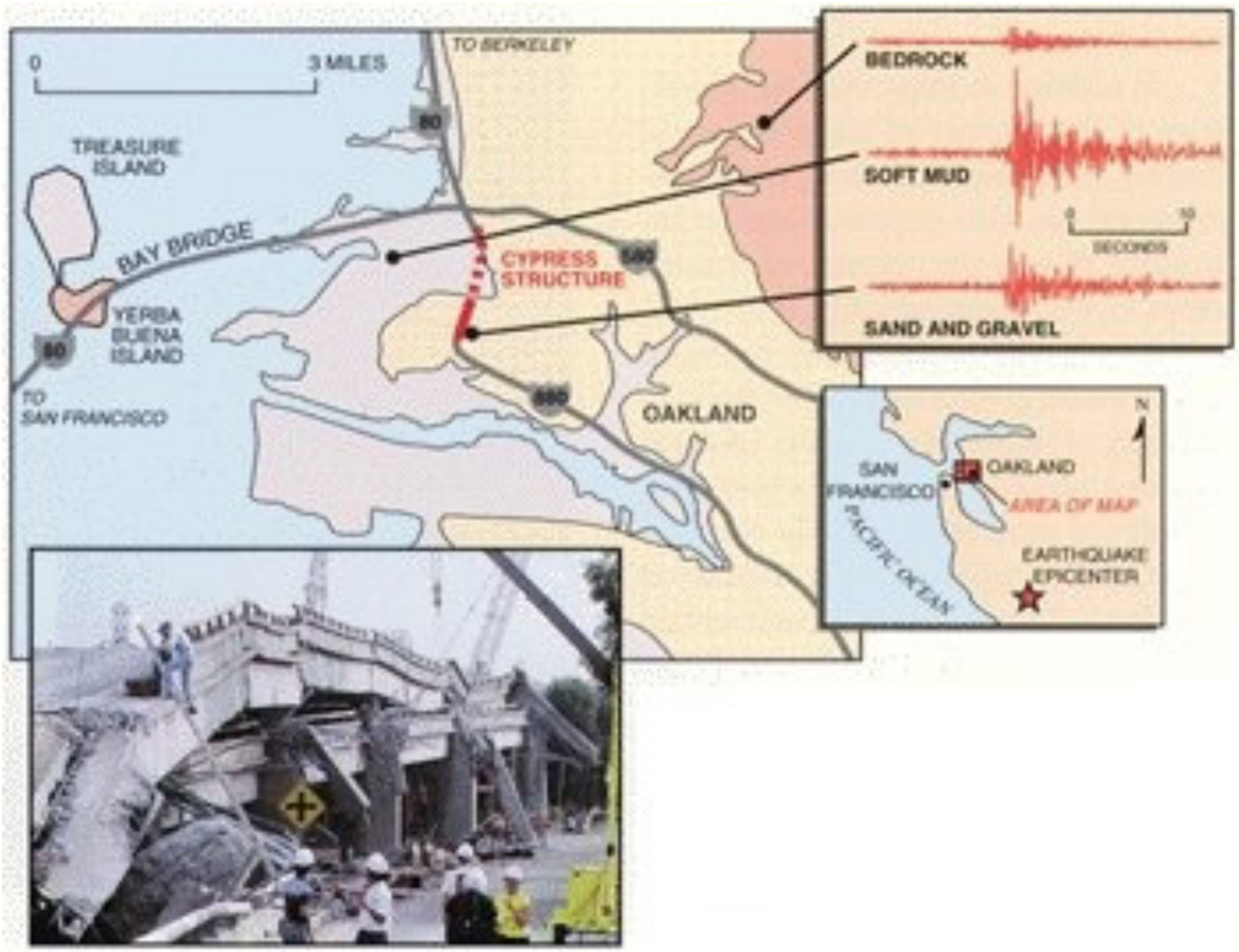
REINFORCED CONCRETE

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9



- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and would **often drive this on Nimitz freeway to meetings** in Oakland

Structural Failure Analysis

REINFORCED CONCRETE

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

The critical failure in this design was that this connection being reinforced concrete, when subjected to seismic oscilating loads, resulted in the concrete crumbling away and leaving only a bundle of rebar to hold up the enormous weight of the upper deck

- NOTE: J Wunderlich worked for PSI inc. as a Structural and Environmental Engineer up until one year before this earthquake, and **would often drive on this Nimitz freeway to meetings** in Oakland

Structural Failure Analysis

STEEL

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

NOTE: J Wunderlich worked for PSI inc. in LaFayette CA as a Structural and Environmental Engineer up until one year before this earthquake, and often **commuted over this bridge at the time of this earthquake**

Structural Failure Analysis

STEEL

- 1989 San Francisco Bay Area Earthquake
  - "Loma Prieta Earthquake," Magnitude 6.9

NOTE: J Wunderlich worked for PSI inc. in LaFayette CA as a Structural and Environmental Engineer up until one year before this earthquake, and often **commuted over this bridge at the time of this earthquake**

STEEL

- 1987 San Francisco Earthquake

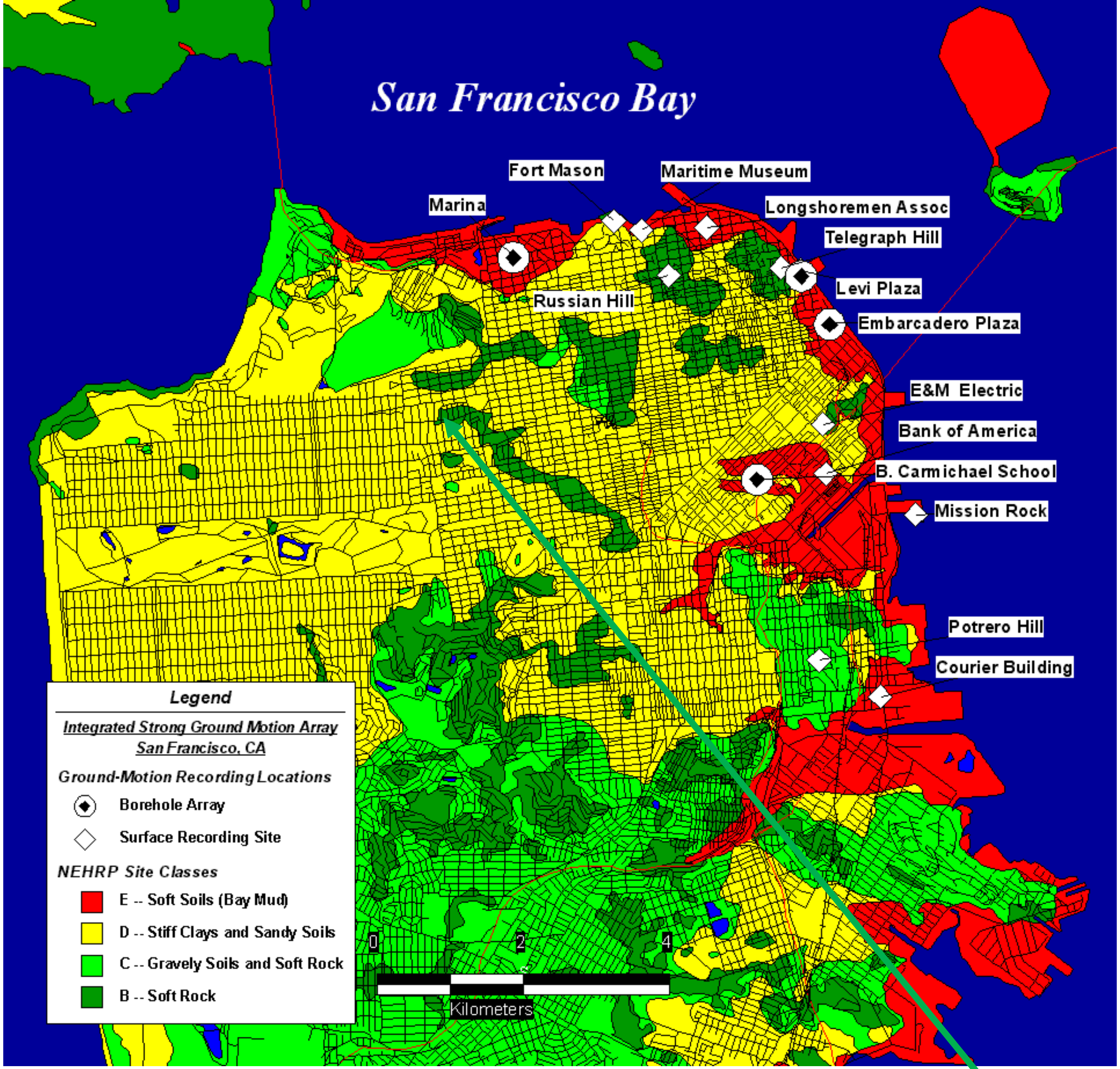
The critical failure in this design was that these types of connections were simply riveting together huge heavy sections of roadway.

Oscillating seismic lateral forces *(and likely some tensile forces due to overall land movement)* sheared rivets.

NOTE: J Wunderlich worked for PSI inc. in LaFayette CA as a Structural and Environmental Engineer up until one year before this earthquake, and often **commuted over this bridge at the time of this earthquake**

PREPARE !

Soft or Sandy soils are subject to LIQUIFACTION when subjected to seismic forces … the soil acts like a liquid, and structures fail !



NOTE: J Wunderlich worked for PSI inc. in LaFayette CA as a Structural and Environmental Engineer up until one year before this earthquake, and **had a map like this, and a EARTHQUAKE PLAN, on kitchen wall**