Lecture 2

January 19, 2006

In this lecture

- Seismic force evaluation
- Procedure in codes
- Limitations of IS 1893:1984

Seismic force evaluation

- During base excitation
  - Structure is subjected to acceleration
- From Newton's second law
  - Force = mass x acceleration
- Hence, seismic force acting on structure

  = Mass x acceleration

Seismic force evaluation

- For design, we need maximum seismic force
- Hence, maximum acceleration is required
  - This refers to maximum acceleration of structure
  - This is different from maximum acceleration of ground
  - Maximum ground acceleration is termed as **peak ground acceleration,** PGA
  - Maximum acceleration of **rigid structure** is same as PGA.

Seismic force evaluation

- Seismic force = mass x maximum acceleration
  - Can be written as:
- Force = (maximum acceleration/g) x (mass x g)

  = (maximum acceleration/g) x W
  - W is weight of the structure
  - g is acceleration due to gravity
- Typically, codes express design seismic force as:

$$V = (A_h) \times (W)$$

  - V is design seismic force, also called design base shear
  - A_h is base shear coefficient

- Maximum acceleration of structure depends on
  - Severity of ground motion
  - Soil conditions
  - Structural characteristics
    - *These include time period and damping*
    - *More about time period, later*
- Obviously, base shear coefficient, A_h, will also depend on these parameters

Seismic force evaluation

- Seismic design philosophy is such that, design seismic forces are much lower than actual seismic forces acting on the structure during severe ground shaking
  - Base shear coefficient has to ensure this reduction in forces
- Hence, base shear coefficient would also have a parameter associated with design philosophy

- Thus, base shear coefficient depends on:
  - Severity of ground motion
  - Soil condition
  - Structural characteristics
  - Design philosophy

- Let us examine how following codes have included these parameters in base shear coefficient
  - IS 1893 (Part 1): 2002
  - IS 1893:1984
  - International Building code (IBC) 2003 from USA
- Study of IBC provisions will help us understand the present international practice

IS 1893 (Part 1):2002

- $A_h = (Z/2).\ (I/R).\ (S_a/g)$
  - Z is zone factor
  - I is importance factor
  - R is response reduction factor
  - S_a/g is spectral acceleration coefficient

- Zone factor, Z
  - Depends on severity of ground motion
  - India is divided into four seismic zones (II to V)
  - Refer Table 2 of IS 1893(part1):2002
  - Z = 0.1 for zone II and Z = 0.36 for zone V

- Importance factor, I
  - Ensures higher design seismic force for more important structures
  - Values for buildings are given in Table 6 of IS :1893
    - *Values for other structures will be given in respective parts*
    - *For tanks, values will be given in Part 2*

- Response reduction factor, R
  - Earthquake resistant structures are designed for much smaller seismic forces than actual seismic forces that may act on them. This depends on
    - *Ductility*
    - *Redundancy*
    - *Overstrength*
  - See next slide

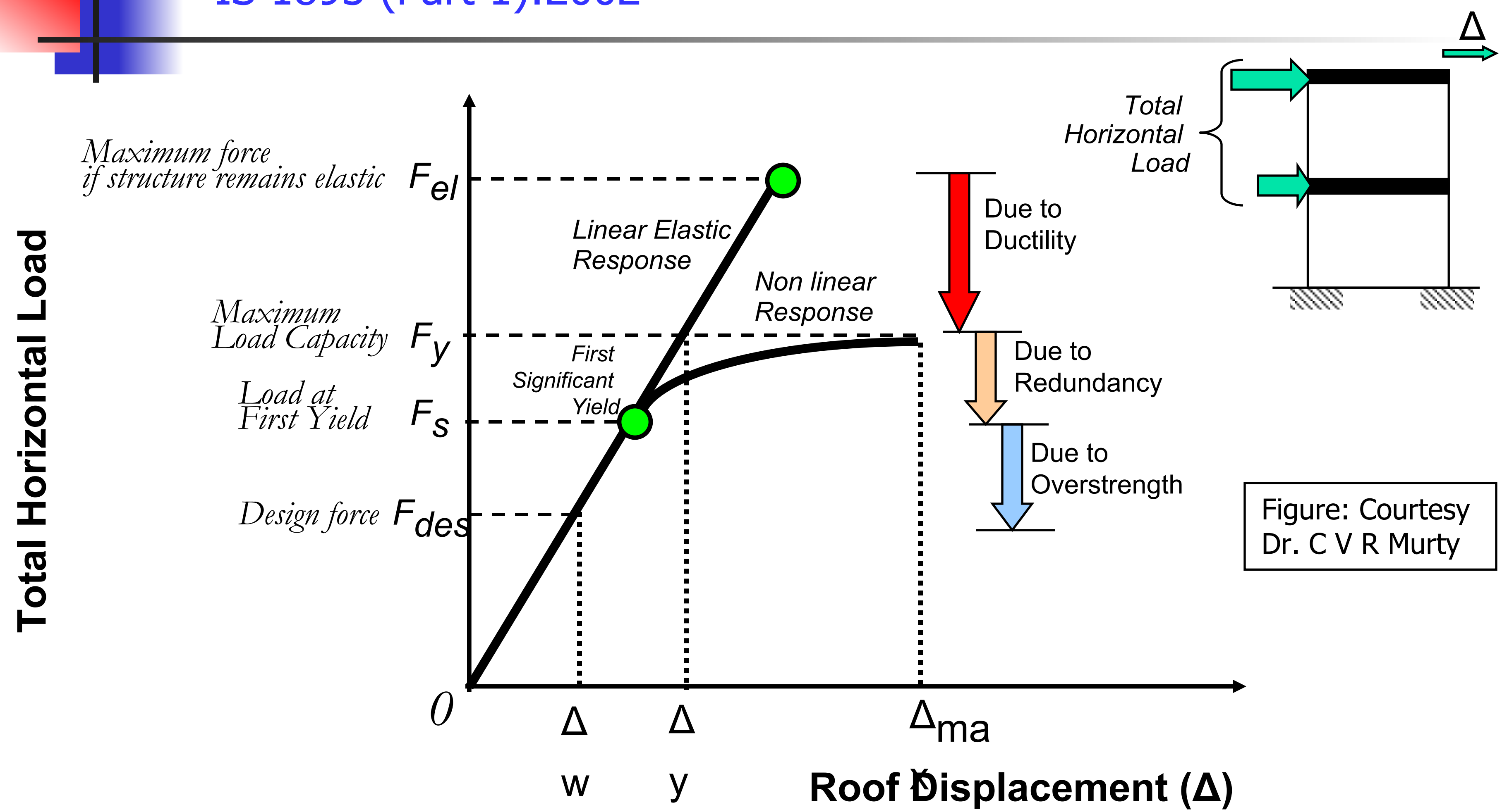


Figure: Courtesy Dr. C V R Murty

$$\text{Response Reduction Factor} = \frac{\text{Maximum Elastic Force } (F_{el})}{\text{Design Force } (F_{des})}$$

- Response reduction factor (contd..)
  - A structure with good ductility, redundancy and overstrength is designed for smaller seismic force and has higher value of R
    - *For example, building with SMRF has good ductility and has R = 5.0 as against R = 1.5 for unreinforced masonry building which does not have good ductility*
  - Table 7 gives R values for buildings
    - *For tanks, R values will be given in IS:1893 (Part 2)*

- Spectral acceleration coefficient, S_a/g
  - Depends on structural characteristics and soil condition
    - *Structural characteristics include time period and damping*
  - Refer Fig. 2 and Table 3 of IS:1893
  - See next slide

IS 1893 (Part 1):2002

For 5% damping

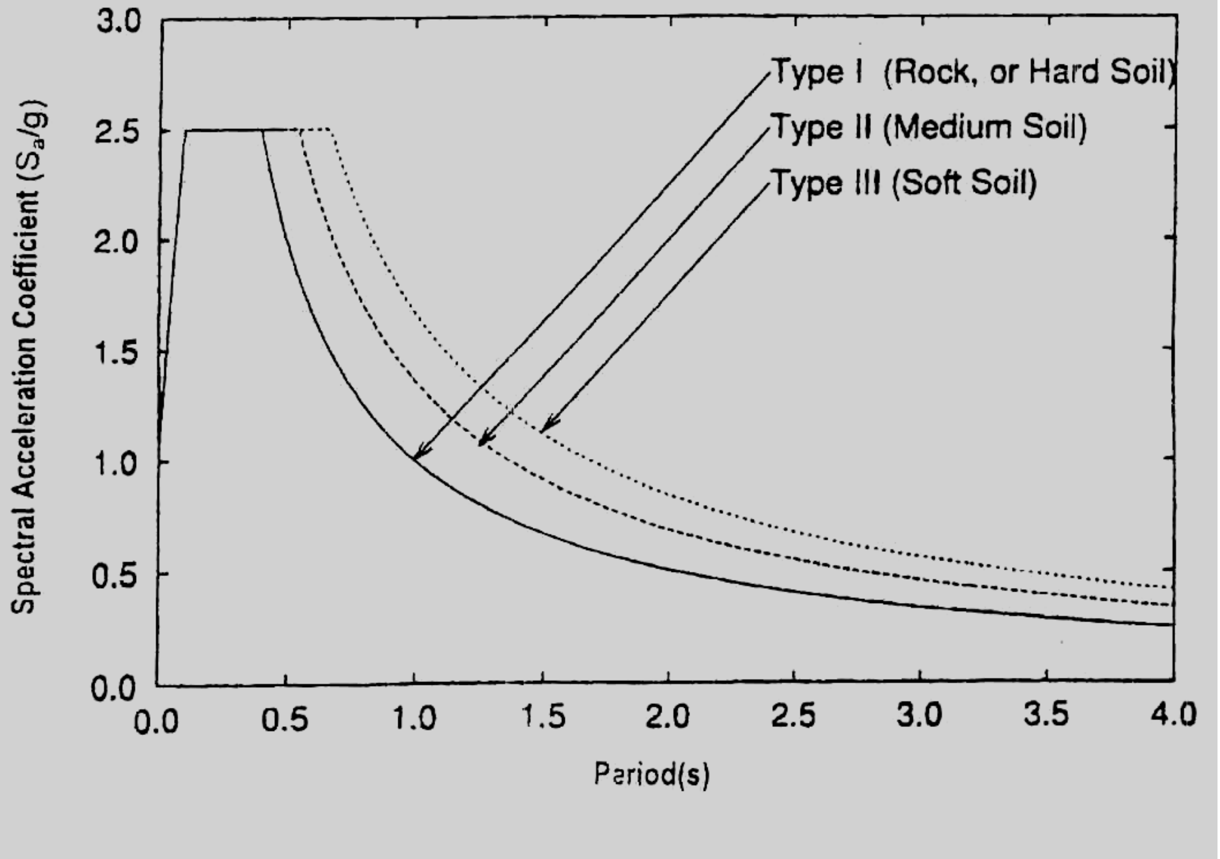


FIG. 2 RESPONSE SPECTRA FOR ROCK AND SOIL SITES FOR 5 PERCENT DAMPING

IS 1893 (Part 1):2002

- For other damping, S_a/g values are to be multiplied by a factor given in Table 3 of IS: 1893
  - Table 3 is reproduced below

% damping	0	2	5	7	10	15	20	25	30
Factor	3.20	1.40	1.00	0.90	0.80	0.70	0.60	0.55	0.50

  - For higher damping, multiplying factor is less
  - Hence, for higher damping, S_a/g is less

IS 1893:1984

- Let us now look at the provision of IS 1893: 1984
- IS 1893:1984 suggests two methods for calculating seismic forces
  - Seismic coefficient method (SCM)
  - Response spectrum method (RSM)
- These have different expressions for base shear coefficient

IS 1893:1984

- $A_h = KC\beta I\alpha_o$ Seismic Coefficient Method (SCM)
  $= K\beta I F_o S_a/g$ Response Spectrum Method (RSM)
  - K is performance factor
  - C is a coefficient which depends on time period
  - β is soil-foundation system coefficient
  - I is importance factor
  - α_o is seismic coefficient
  - F_o is zone factor
  - S_a/g is average acceleration coefficient

IS 1893:1984

- Seismic coefficient, α_o
  - Depends on severity of ground motion
  - Used in seismic coefficient method
- Zone factor, F_o
  - Depends on severity of ground motion
  - Used in response spectrum method

IS 1893:1984

Table Values of Basic Seismic Coefficient and Seismic Zone Factor

Serial No.	Zone No.	Basic Horizontal Seismic Coefficient* α_0	Seismic Zone Factor† F_0
1	V	0.08	0.40
2	IV	0.05	0.25
3	III	0.04	0.20
4	II	0.02	0.10
5	I	0.01	0.05

*For seismic coefficient method.
†For response spectrum method.

- β is soil foundation coefficient
  - Depends on type of soil and foundation
    - *In IS 1893:2002, type of foundation does not have any influence on base shear coefficient*

Table Values of β for Different Soil-Foundation Systems

Serial No.	Type of Foundation	Rock/ Hard Soils	Medium Soils	Soft Soils
1	Piles passing through any soil but resting on rock or hard soil	1.0	1.0	1.0
2	Piles not covered above	–	1.0	1.2
3	Raft foundations	1.0	1.0	1.0
4	Combined or isolated R.C. footings with tie beams	1.0	1.0	1.2
5	Isolated R.C. footings without tie beams or unreinforced strip foundations	1.0	1.2	1.5
6	Caisson foundation	1.0	1.2	1.5

- Importance factor, I
  - Ensures higher design seismic force for more important structures
    - *IS 1893 (Part 1):2002, gives values only for buildings*

Table Values of Importance Factor *I*

Serial No.	Structure	*I*
1	Dams (all types)	3.0
2	Containers of inflammable or poisonous gases or liquids	2.0
3	Important service and community structures, such as hospitals, water towers and tanks; schools, important bridges, important power houses, monumental structures; emergency buildings like telephone exchanges and fire bridges; large assembly structures like cinemas, assembly halls, and subway stations	1.5
4	All others	1.0

- Performance factor, K
  - Depends on ductility of structure
    - *Similar to response reduction factor of IS1893(Part 1):2002*
    - *K is in numerator whereas, R is in denominator*
  - For buildings with good ductility, K = 1.0
  - For ordinary buildings, K = 1.6
  - Thus, a building with good ductility will have lower value of base shear coefficient than ordinary building

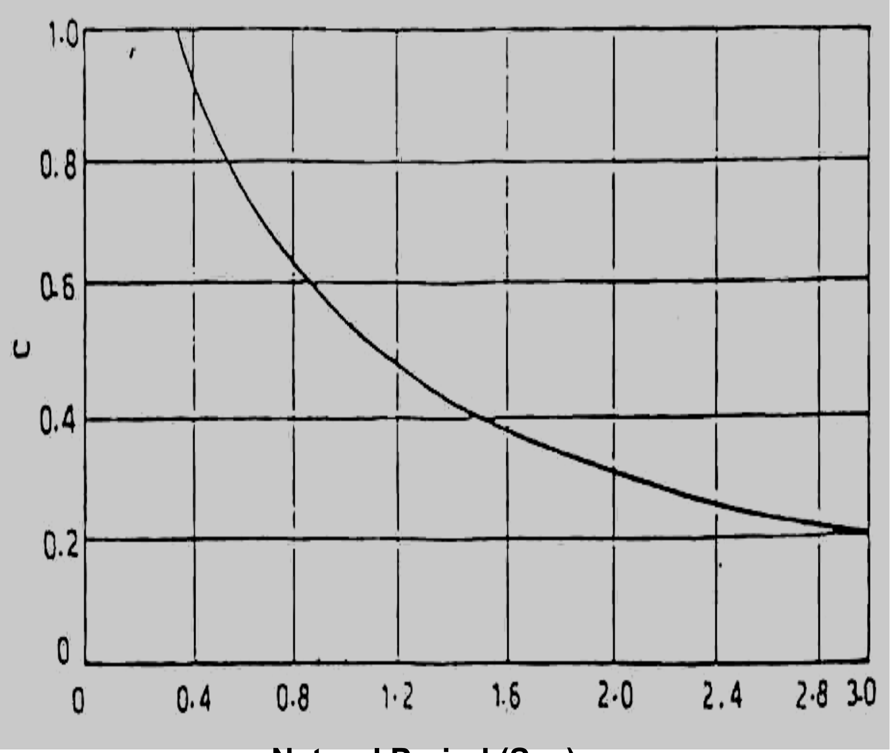
IS 1893:1984

Table Values of Performance Factor *K*

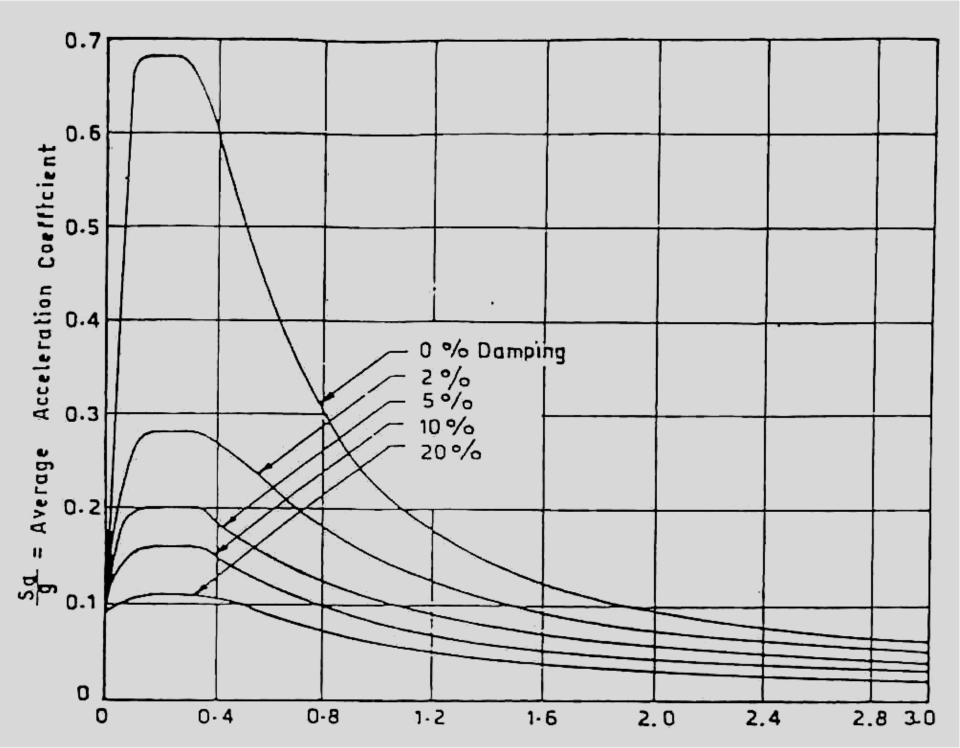
Serial No.		Structure	*K*
1	a.	Moment-resistant frame with appropriate ductility details as given in IS:4326-1976 in reinforced concrete or steel	1.0
	b.	Frame as above with R.C. shear walls or steel bracing members designed for ductility	1.0
2	a.	Frame as in 1a with either steel bracing members or plain or nominally reinforced concrete infill panels	1.3
	b.	Frame as in 1a in combination with masonry infills	1.6
3		R.C. framed buildings not covered by 1 or 2 above	1.6

- Coefficient, C
  - Depends on time period
  - see next slide
- Spectral acceleration, S_a/g
  - Depends on time period and damping
  - See next slide

- Graphs for C and S_a/g from IS 1893:1984



Natural Period (Sec)



Natural Period (Sec)

IS 1893:1984

- IS 1893:1984 has provisions for elevated tanks only
  - Ground supported tanks are not considered
- For elevated tanks, it suggests

$$A_h = \beta I F_o S_a / g$$

  - Performance factor, K is not present
  - Implies, K = 1.0 for all types of elevated tanks
    - *Unlike buildings, different types of tanks do not have different values of K*
  - This is one of the major limitation of IS1893: 1984
    - *More about it, later*

IBC 2003

- International Building Code (IBC) 2003
  - In *IITK-GSDMA* guidelines IBC 2000 is referred
  - This is now upgraded to IBC 2003
    - *In USA codes are regularly upgraded every three year*
  - There is no change in the base shear coefficient expression from IBC 2000 to IBC 2003

- Base shear coefficient

$$A_h = S_{D1}\, I/(R\, T)$$
$$\leq S_{DS}\, I/R$$

- A_h shall not be less than 0.044 $S_{DS}I$ for buildings and not less than 0.14 $S_{DS}I$ for tanks
  - This is a lower limit on A_h
  - It ensures minimum design seismic force
  - This lower limit is higher for tanks than for buildings
- Variation with time period is directly given in base shear coefficient
  - Hence, no need to have response spectrum separately

- T is time period in seconds
- S_{DS} and S_{D1} are design spectral accelerations in short period and at 1 sec. respectively
  - S_{DS} and S_{D1} depend on seismic zone and soil
- I is importance factor and R is response modification factor
  - IBC suggests I = 1.0, 1.25 and 1.5 for different types of structures
  - Values of R will be discussed later

- More about S_{DS} and S_{D1}
  - $S_{DS} = 2/3\ F_a\ S_S$ and $S_{D1} = 2/3\ F_v\ S_1$
  - S_S is mapped spectral acceleration for short period
  - S_1 is mapped spectral acceleration for 1-second period
  - S_S and S_1 are obtained from seismic map
    - *This is similar to zone map of our code*
    - *It is given in contour form*
  - F_a and F_v are site coefficients
    - *Their values for are given for different soil types*

- Response modification factor, R
  - IS 1893(Part 1):2002 calls it response reduction factor
  - Values of R for some selected structures are given in next slide

IBC 2003

Type of structure	***R***
Building with special reinforced concrete moment resisting concrete frames	8.0
Building with intermediate reinforced concrete moment resisting concrete frames	5.0
Building with ordinary reinforced concrete moment resisting concrete frames	3.0
Building with special steel concentrically braced frames	8.0
Elevated tanks supported on braced/unbraced legs	3.0
Elevated tanks supported on single pedestal	2.0
Tanks supported on structural towers similar to buildings	3.0
Flat bottom ground supported anchored steel tanks	3.0
Flat bottom ground supported unanchored steel tanks	2.5
Ground supported reinforced or prestressed concrete tanks with reinforced nonsliding base	2.0

Base shear coefficient

- In summary,
  - Base shear coefficient from these three codes are:

IS 1893 (Part 1): 2002	IS 1893: 1984	IBC2003
$A_h = (Z/2).(I/R).(S_a/g)$	SCM: $A_h = KC\beta I\alpha_o$ RSM: $A_h = K\beta IF_oS_a/g$ For tanks: $A_h = \beta IF_oS_a/g$	$A_h = S_{D1}\ I/(R\ T)$ $\leq S_{DS}\ I/R$ $> 0.044\ S_{DS}\ I$ for buildings $> 0.14\ S_{DS}\ I$ for tanks

- Important to note that:
- IS codes specify base shear coefficient at working stress level
  - For limit state design, these are to be multiplied by load factors to get factored loads
- IBC specifies base shear coefficient at ultimate load level
  - For working stress design, seismic forces are divided by a factor of 1.4

Base shear coefficient

- Once, base shear coefficient is known, seismic force on the structure can be obtained
  - Recall, seismic force, $V = A_h . W$
  - This is same as force = mass x acceleration

Base shear coefficient

- Let us compare base shear coefficient values from these codes
  - Comparison will be done at working stress level
    - *IBC values are divided by 1.4 to bring them to working stress level*
  - This shall be done for similar seismic zone or seismic hazard level of each code
  - This comparison is first done for buildings

- Comparison for buildings
  - Following parameters are chosen

IS 1893 (Part 1): 2002	IS 1893: 1984	IBC2003
Z = 0.36; Zone V I = 1.0; R = 5.0 Soft soil 5% damping	α_o = 0.08; F_o = 0.4; Zone V β = 1.0 K = 1.0; I = 1.0 Soft soil, raft foundation 5% damping	S_{Ds} = 1.0; S_{D1} = 0.6 I = 1.0; R = 8.0 Soil type D, equivalent to soft soil of IS codes 5% damping

  - They represent similar seismic hazard level

- Building with good ductility is chosen
  - Say, buildings with SMRF
- In IBC, for buildings with SMRF, R = 8.0
  - Refer Table shown earlier

Base shear coefficient

- For building with T = 0.3 sec
- IS 1893(Part 1):2002
  - $S_a/g = 2.5$
  - $A_h = Z/2.I/R.S_a/g =$ *(0.36/2)x (1.0/5.0) x 2.5 =* ***0.09***
- IS 1893:1984
  - C = 1.0 and $S_a/g = 0.2$
  - SCM: $A_h = KC\,\beta I \alpha_o =$ *1.0 x 1.0 x1.0 x1.0x0.08 =* ***0.08***
  - RSM: $A_h = K\,\beta I F_o S_a/g =$ *1.0 x 1.0 x1.0x 0.4x0.2 =* ***0.08***
- IBC 2003
  - $A_h = S$ ... I/(1.4xR) = *1.0 x1.0/(1.4 x 8.0) =*

Base shear coefficient

- For building with T = 1 sec
- IS 1893(Part 1):2002
  - $S_a/g = 1.67$
  - $A_h = Z/2.I/R.S_a/g =$ *(0.36/2)x(1.0/5.0)x1.67 =* ***0.06***
- IS 1893:1984
  - C = 0.53 and $S_a/g = 0.11$
  - SCM: $A_h = KC\beta I\alpha_o =$ *1.0 x0.53x1.0 x1.0x0.08 =* ***0.042***
  - RSM: $A_h = K\beta IF_oS_a/g =$ *1.0x1.0x1.0x0.4x0.11 =* ***0.044***
- IBC 2003
  - $A_h = S_{D1}I/(1.4xRxT) =$ *0.6x1.0/(1.4 x 8.0x1.0) =* ***0.054***

Base shear coefficient

- For building with T = 1.5 sec
- IS 1893(Part 1):2002
  - $S_a/g = 1.11$
  - $A_h = Z/2.I/R.S_a/g =$ *(0.36/2)x(1.0/5.0)x1.11 =* ***0.040***
- IS 1893:1984
  - C = 0.4 and $S_a/g = 0.078$
  - SCM: $A_h = KC\beta I\alpha_o =$ *1.0 x0.4x1.0 x1.0x0.08 =* ***0.032***
  - RSM: $A_h = K\beta IF_oS_a/g =$ *1.0x1.0x1.0x0.4x0.078 =* ***0.031***
- IBC 2003
  - $A_h = S_{D1}I/(1.4RT) =$ *0.6x1.0/(1.4 x 8.0x1.5) =* ***0.036***

Base shear coefficient

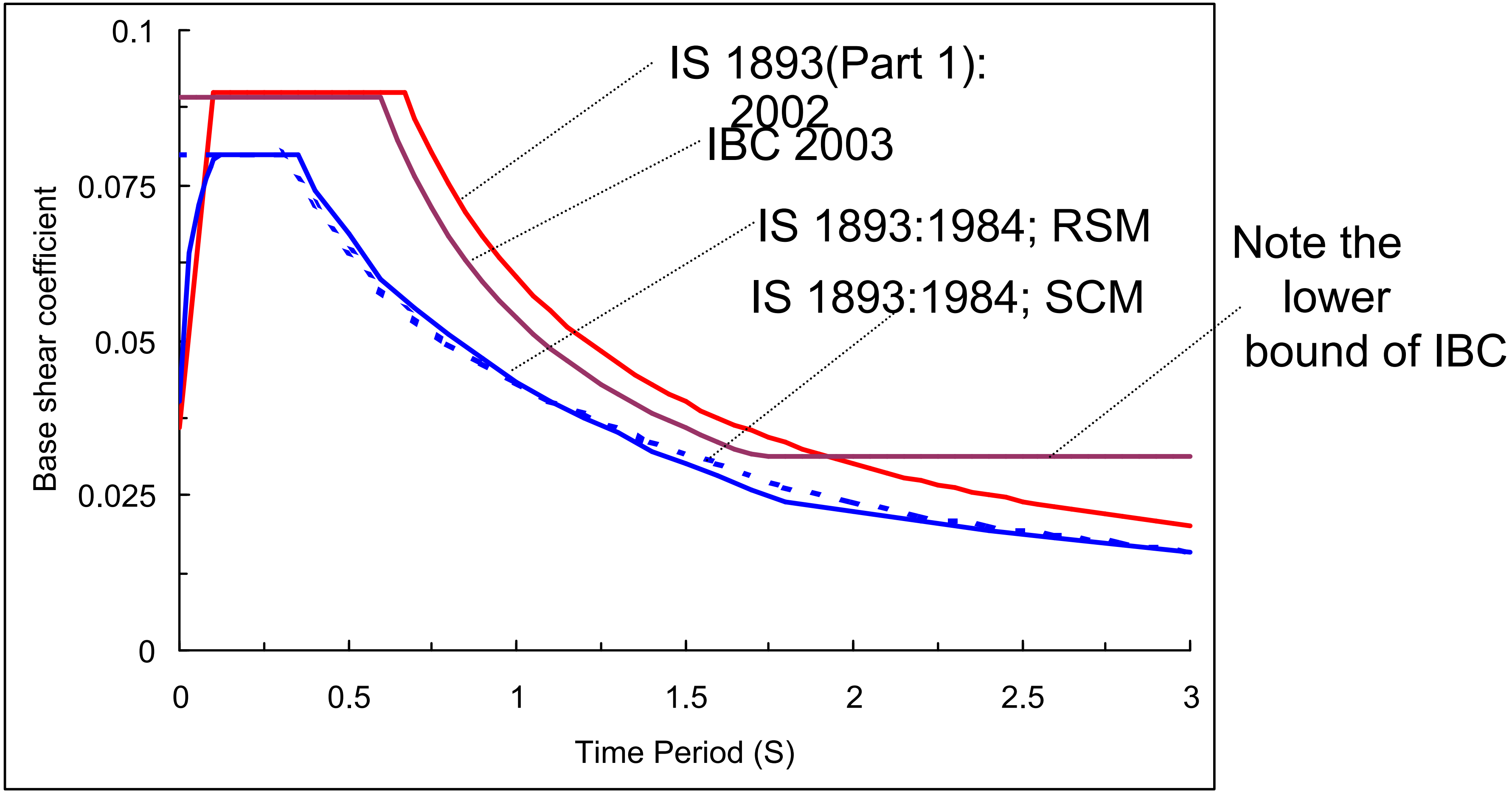
- Base shear coefficients for four time periods

T (Sec)	IS 1893 (Part 1): 2002	IS 1893: 1984		IBC2003
		SCM	RSM	
0.3	0.09	0.08	0.08	0.089
1.0	0.06	0.042	0.044	0.054
1.5	0.040	0.032	0.031	0.036
2.0	0.03	0.024	0.024	0.0314*

* Due to lower bound, this value is higher

- Graphical comparison on next slide

- Comparison of base shear coefficient (Buildings)



Base shear coefficient

- We have seen that:
  - Codes follow similar strategy to obtain design base shear coefficient
  - In similar seismic zones, base shear coefficient for buildings matches reasonably well from these three codes

Base shear coefficient

- Similarly, let us compare design base shear coefficients for tanks
  - From IS1893:1984 and IBC 2003
  - IS 1893(Part 1):2002 is only for buildings
    - *Hence, can't be used for tanks*
  - Only elevated tanks will be considered
    - *IS 1893:1984 has provisions for elevated tanks only*
  - Zone and soil parameters will remain same as those considered for buildings
  - Importance factor for tanks are different than those for buildings

Base shear coefficient

- In IBC
  - I = 1.25 for tanks
  - R = 3.0 for tanks on frame staging (braced legs)
  - R = 2.0 for tanks on shaft or pedestal
- In 1893:1984
  - I = 1.5 for tanks
  - K is not present in the expression for base shear coefficient (implies k=1.0). Hence, base shear coefficient will be same for all types of elevated tanks

Base shear coefficient

- For tank with T = 0.3 sec
- IS 1893:1984
  - I = 1.5, S_a/g = 0.2
  - $A_h = \beta I F_o S_a/g$ = *1.0 x 1.5 x 0.4x0.2 =* ***0.12***
  - This value is common for frame and shaft staging
- IBC 2003
  - For frame staging, I = 1.25, R = 3.0

    $A_h = S_{DS} I/(1.4xR)$ = *1.0 x1.25/(1.4 x 3.0) =* ***0.298***
  - For shaft staging, I = 1.25, R = 2.0

    $A_h = S_{DS} I/(1.4xR)$ = *1.0 x1.25/(1.4 x 2.0) =* ***0.446***

Base shear coefficient

- For tank with T = 1 sec
- IS 1893:1984
  - I = 1.5, $S_a/g = 0.11$
  - $A_h = \beta I F_o S_a/g =$ *1.0x1.5x0.4x0.11 =* ***0.066***
- IBC 2003
  - For frame staging, I = 1.25, R = 3.0

    $A_h = S_{D1} I/(1.4xRxT) =$ *0.6x1.25/(1.4 x 3.0x1.0) =* ***0.178***
  - For shaft staging, I = 1.25, R = 2.0

    $A_h = S_{D1} I/(1.4xRxT) =$ *0.6x1.25/(1.4 x 2.0x1.0) =* ***0.268***

- Base shear coefficients for tanks

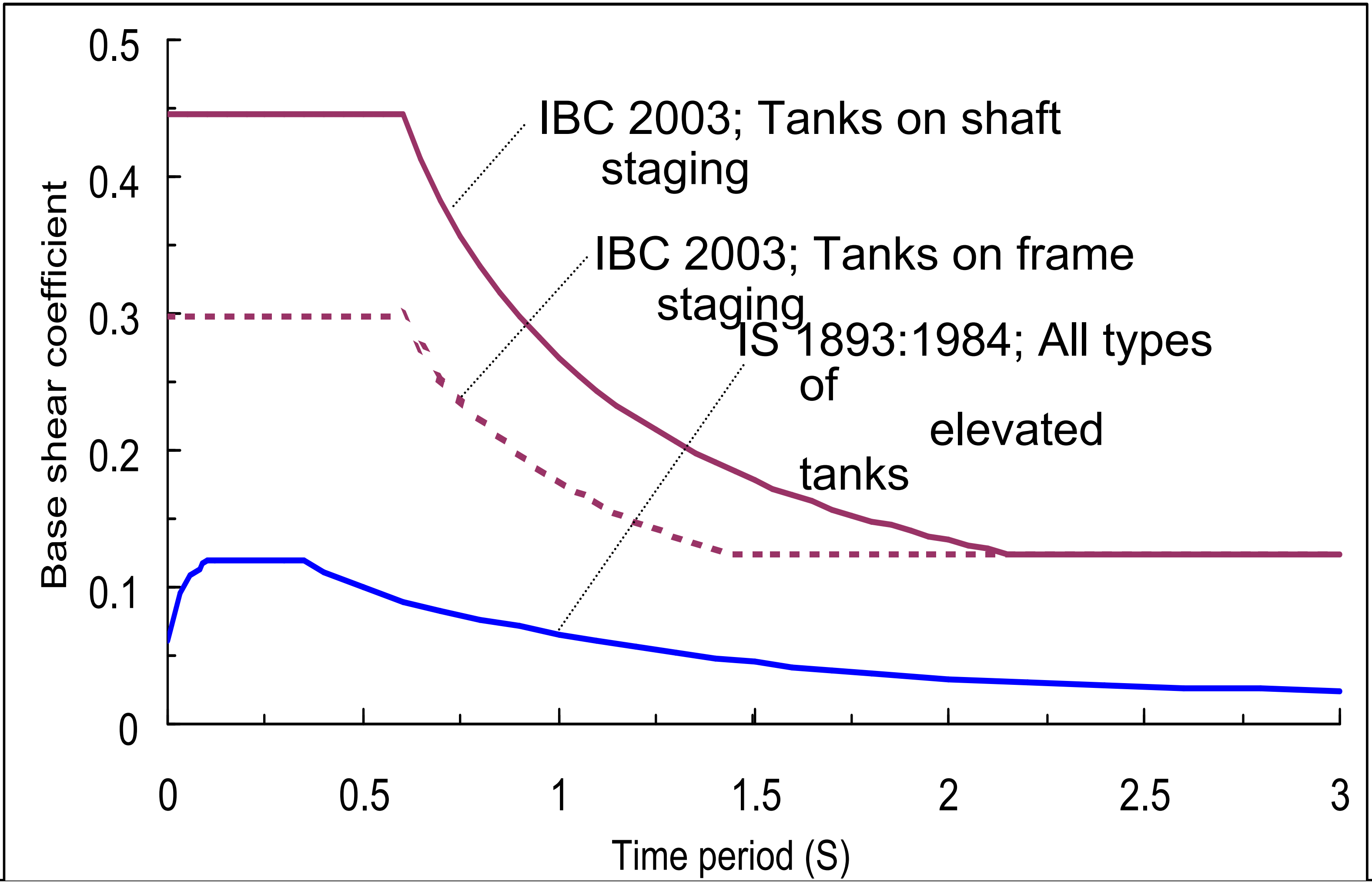
T (Sec)	IS 1893: 1984*	IBC 2003	
		Frame staging	Shaft staging
0.3	0.12	0.298	0.446
1.0	0.066	0.178	0.268

* Base shear coefficient values are common for frame and shaft staging

- Graphical comparison on next slide

Base shear coefficient

- Comparison of base shear coefficient (Tanks)



Base shear coefficient

- Base shear coefficient for elevated tanks from IS1893:1984 is on much lower side than IBC 2003
- IBC value is about 2.5 times for frame staging and 3.5 times for shaft staging than that from IS1893:1984
  - Recall, for buildings, IS 1893:1984 and IBC have much better comparison

Base shear coefficient

- Reason for lower values in IS 1893:1984
  - IBC uses R = 2.0 and R = 3.0 for tanks as against R = 8.0 for buildings with good ductility
  - IS 1893:1984 uses K = 1.0 for tanks. Same as for buildings with good ductility.
  - Clearly ,elevated tanks do not have same ductility, redundancy and overstrength as buildings.
- This is a major limitation of IS 1893:1984

Base shear coefficient

- Another limitation of IS 1893:1984
  - In Lecture 1, we have seen, liquid mass gets divided into impulsive and convective masses
  - IS 1893:1984, does not consider convective mass
  - It assumes entire liquid mass will act as impulsive mass, rigidly attached to wall
- In *IITK-GSDMA* guidelines, these limitations have been removed

Base shear coefficient

- Let us now, get back to seismic force evaluation for tanks
- Design base shear coefficient is to be expressed in terms of parameters of IS 1893(Part 1):2002
  - $A_h = (Z/2). (I/R). S_a/g$
  - Z will be governed by seismic zone map of Part 1
  - I and R for tanks will be different from those for buildings
    - *R depends on ductility, redundancy and overstrength*
  - S_a/g will depend on time period

Base shear coefficient

- Impulsive and convective masses will have different time periods
  - Hence, will have different S_a/g values
  - Procedure for finding time period in next lecture

At the end of Lecture 2

- Seismic force = (A_h) X (W)
- Base shear coefficient, A_h, depends on
  - Seismic Zone
  - Soil type
  - Structural characteristics
  - Ductility, Redundancy and overstrength
- IS 1893:1984 has some serious limitations in design seismic force for tanks