Course on Design of Steel Structures

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Lecture 31
Module 7
Compressive Strength

Hello, now I am going to discuss about the design strength of compression member, in last class I have discussed different factors effecting compressive strength in a compression member. So from the earlier discussions we have seen the main three parameters which are effecting on the on the compressive strength of a member, one is the material strength of the member that means what is the yield strength of the member depending on that the compressive strength will vary.

So while calculating the compressive strength or while developing the expression for compressive strength we need to calculate means we need to consider the material strength that is yield strength.

Next factor is the slenderness ratio, we have seen from the Eulers critical load and Eulers buckling formula that the compressive strength varies inversely with the slenderness ratio. So while developing the compressive strength formula means the expression for compressive strength we need to incorporate the slenderness ratio in that also, this is this has to be taken care.

Another aspects which are of the importance we have to give that is the local buckling because one is crushing, another is overall buckling, another is local buckling. So because of the configuration of the member cross section of the member the local buckling of the flange or web may happen. So that aspects has to also be taken care in the derivation of the expression for compressive strength.

So these three aspects has to be considered and we have to develop a means develop a reasonable accurate formula and that formula should be capable of reflecting the actual behaviour.

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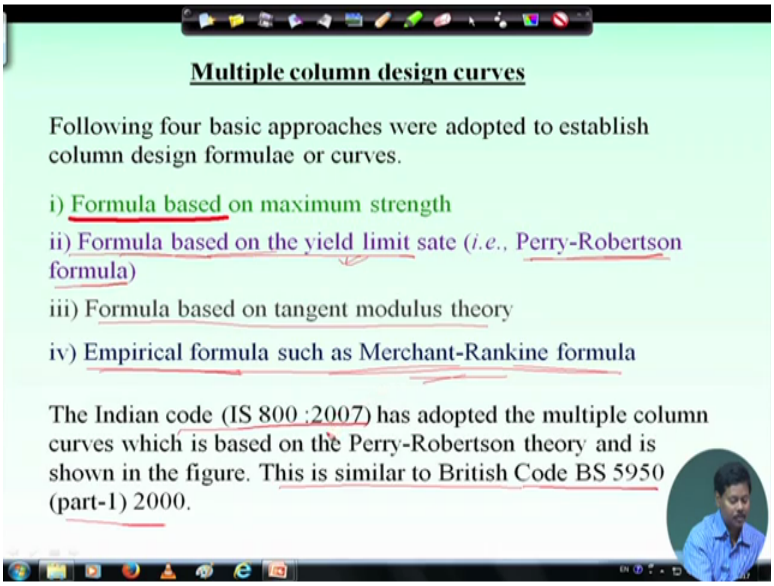

So let us see how people have started developing formula and what we are adapting. So four different approaches have been considered for finding the design column formula. So one is the formula based on the maximum strength, this is one approach in which people have tried, another is formula based on the yield limit, which is called Perry-Robertson formula and basically this approach was is considered by our Indian Code the IS 800:2007 has also adapted the multiple column curves based on the Perry Robertson formula and this is basically similar to the British code BS 5950 (part-1) 2000.

This the formula which have been derived is similar to the British code and the formula was prescribed by Perry-Robertson who has proposed. So this has been adapted but we will discuss about this in details and another two formula are also adapted to establish column design formula that is formula based on tangent modulus theory and Empirical formula such as Merchant-Rankine formula. So these four basic approach are observed to establish column design formula and we may recall the earlier code that is IS 800:1984, which was established as per Merchant-Rankine formula.

So before going to this new version we will shortly discuss about the Merchant-Rankine formula, how the earlier code was adapted this one and then we will come to this formula.

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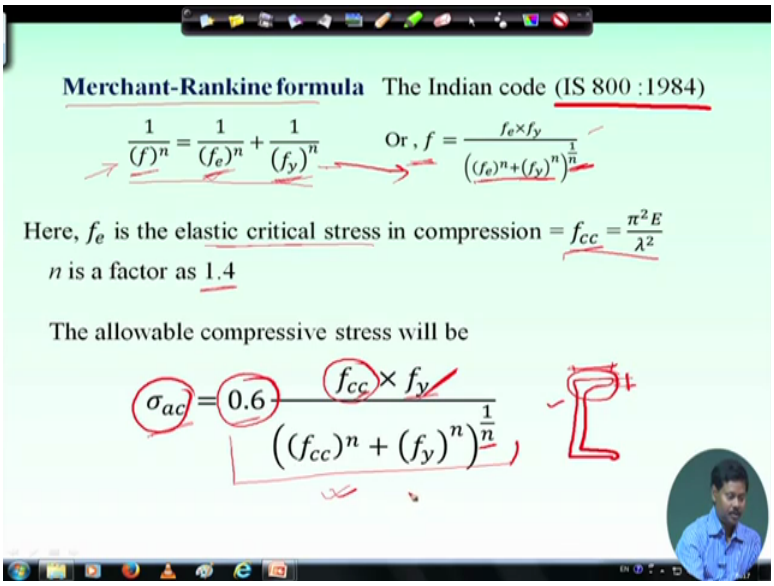

So in IS 800:1984 Merchant-Rankine formula was adapted where we know the basic formula was like this that 1 by f whole to the power n is equal to 1 by fe whole to the power n plus 1 by fy whole to the power n, if two this is elastic stress fe is the elastic stress and fy is the yield stress. So considering two stress, one is elastic stress and yield stress the equivalent stress f can be related as this formula that is 1 by f to the power n is equal to 1 by fe to the power n plus 1 by fy to the power n.

So from this we can write f as fe into fy by square root of fe to the power n plus fy to the power n not square root of whole to the power 1 by n. So f is equal to fe into fy by fe to the power n plus fy to the power n whole to the power 1 by n. So if we derive this from this formula we will get finally this one, okay I am not going into details, where fe is the elastic critical stress and which was developed by the Eulers formula that is fcc is equal to pi square E by lambda square.

This we have discussed in the last class that is fcc how to find out fcc from Eulers formula this has been discussed so this will be used here that is Eulers formula that is fcc is equal to pi square E by lambda square will be this will be used here, right. And n is a factor which is taken as 1.4, right.

So considering this the allowable compressive stress in IS code has proposed like this that is 0.6 into (fcc) by into fy by fcc to the power n plus fy to the power n whole to the power 1 by n. Now this 0.6 has been taken as a factor of safety and n we can consider as 1.4, so allowable compressive stress in compression member sigma SE was consider as this as this formula according to IS 800:1984. Here we can see that two things has been taken care, one is the material property the material strength which is the yield strength as fy and another is the fcc that is elastic critical stress which comes from buckling.

So buckling global buckling and the squashing effect has been taken into consideration but another important parameter which has not been considered is the geometrical configuration of the cross section of the member. Say for example this is a cross section of the member, now geometrical configuration means we have to see what is the thickness of the flange, what is the width of the flange, what is the ratio and as per that it may happen that local buckling could happen.

So before crushing or global buckling local due to local buckling the member may fail which from this formula it is not possible to it is not possible to capture.

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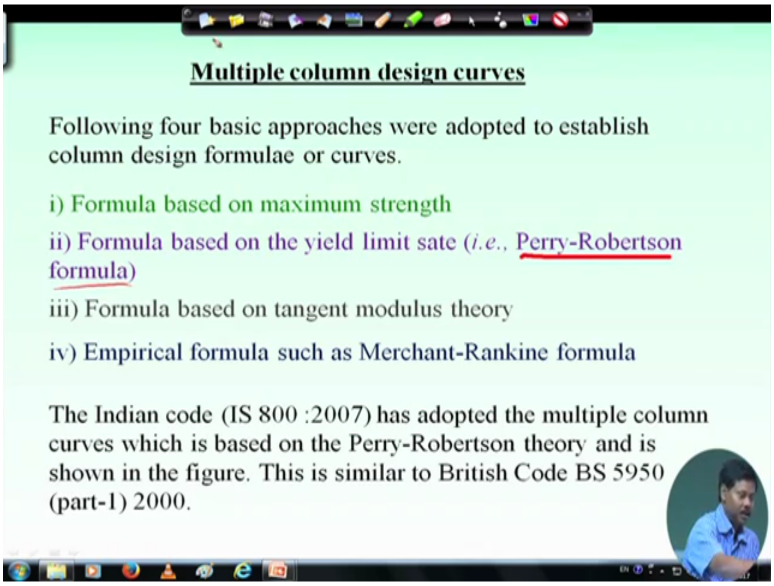

Therefore this formula we are no longer using, we are using the new developed formula which was based on which is based on Perry-Robertson formula. So according to Perry-Robertson formula this few things has been (consi) sorry.

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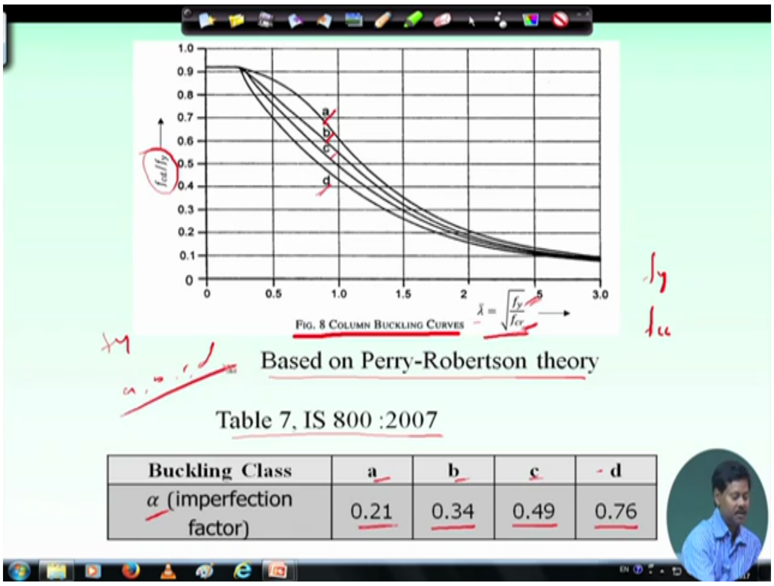

According to Perry-Robertson formula the multiple design curve has been adapted by the IS code, in IS code figure 8 in IS code IS 800:2007 these column buckling curves are given and this is based on the Perry-Robertson theory. According to Perry-Robertson theory three things has been considered as I told one is the material strength fy, another is the the elastic critical buckling fcc and another is the local buckling and this local buckling has been considered in terms of this class a, b, c, d we can see here four type of graphs have been proposed depending on the buckling class the four graphs are coming and in table 7 this buckling class have been defined, we can see here that according to buckling class a, b, c, d that imperfection factor alpha has been introduced and this alpha value is 0.21 in case of class a, 0.34 in class of b, 0.49 in case of class c and 0.76 in case of class d.

So according to buckling class the imperfection factor has been proposed and according to that imperfection factor the column buckling curve for class a, b, c, d have been derived. Here u can see that along X direction it is lambda bar non-dimensional that is square root of fy by fcr and along y direction fcd by fy where fcd is the design compressive stress and fy is the yield stress and here fy is the yield stress and fcr is the elastic critical stress, right.

So we could see here that based on Perry-Robertson theory we have considered three means we have taken into consideration three effects one is due to material fy, another is due to global buckling and other one is the new component which has been adapted in this code is the class of the structure means buckling class a, b, c, d so according to buckling class this has been changed, right.

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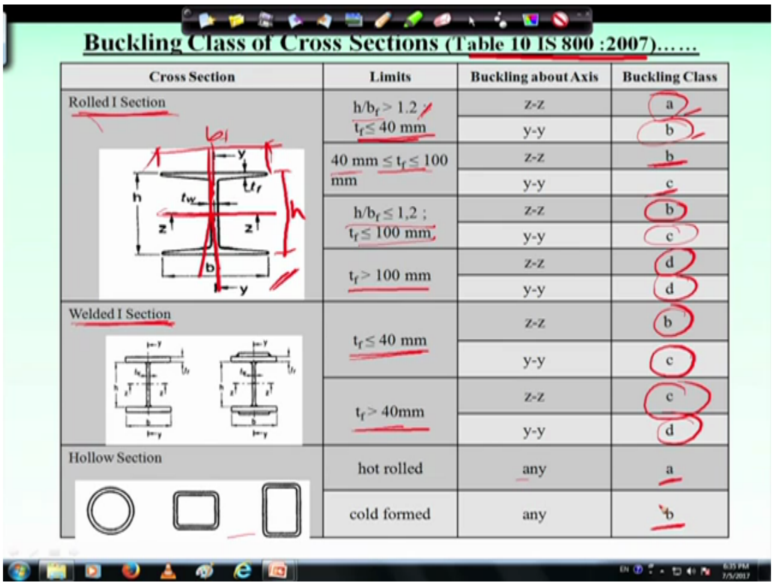

Now coming to the buckling class of cross section we can see that which is given in table 10 of IS 800:2007 in table 10 of IS 800:2007 the different buckling class have been defined according to the cross sectional dimension. Say for rolled I section, this is rolled I section here if h by bf is greater than 1.2 and where h is the total depth from here to here total depth and tf is the this is h and tf bf is the flange width, this is bf flange width, right.

So if h by bf is greater than 1.2 and thickness of flange tf is less than or equal to 40, then about z-z buckling class will be a and about y-y buckling class will be b. Here you see that buckling class along y-y oh sorry about y-y and about z-z is different, this is z-z axis this has been consider and this is y-y axis has been consider. So along z-z axis it is considered as buckling class a, along y-y axis it is considered as buckling class b.

So for the same member the buckling class will be different a and b therefore the value of alpha the imperfection factor alpha will be different for different direction and if the I section in case of I section if the thickness of flange varying from 40 to 100, then about z-z it will be b and about y-y buckling class will be c. Similarly if h by bf is less than 1.2 and tf is less than or equal to 100, then buckling class will be b about z-z axis and c about y-y axis.

And similarly if tf is greater than 100, then buckling class will be d about z-z axis and d about y-y axis as well. So this is how the buckling class have been defined by the code and according to that the imperfection factor has also been mentioned in the code, which has to be taken mean which has been which will be used while developing the design curve of the column, right.

Similarly for weld section weld I section this is rolled I section, this is weld I section. In case of weld I section if tf is less than equal to 40, then buckling class will be b about z-z axis, c about y-y axis and if tf is greater than equal to 40, this will be c and about y-y will be d. Similarly for Hollow section for hot rolled about any axis it will be a and for cold rolled cold formed section it will be b.

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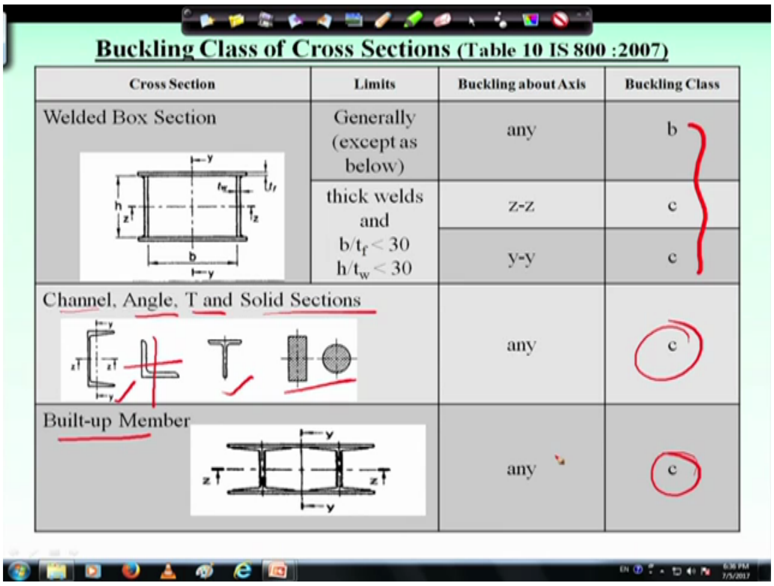

Now coming to weld box section, here also buckling class has been defined. Similarly I am not going into details we can means we can find out in the code, in table 10 only thing I want to mention that when we are using channel section, angle section, T section or some solid section, solid section means rectangular section or circular section then the buckling class will be c about any direction about any direction, say for angle about y-y axis, about z-z axis it will be c for both the direction.

Similarly for channel section also it will be c, for T section also it will be c and for built-up member any direction the buckling class has also been considered as c.

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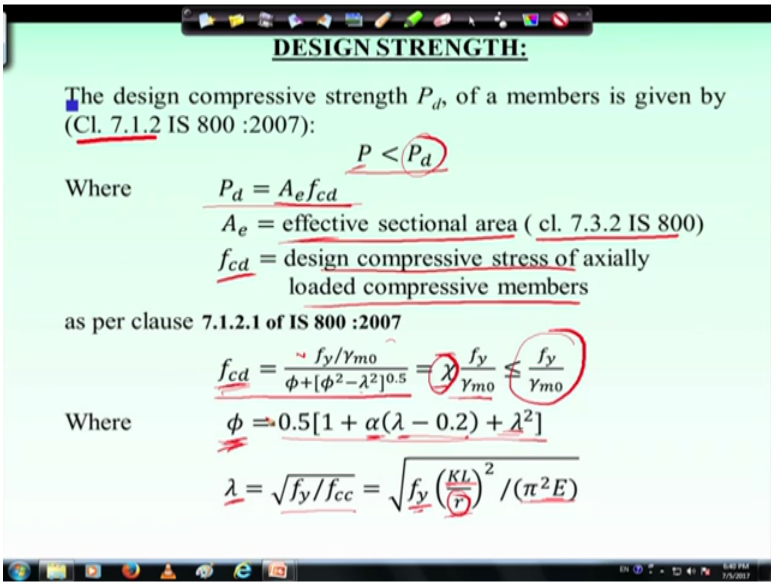

So these are the thing we need to find out from table 10 of IS 800, for calculating the imperfection factor alpha. Now this imperfection factor will be used in this formula the formula has been developed and given in the clause 7.1.2 of IS 800:2007, where it is mentioned that P should be less than Pd where P is the external compressive load and Pd is the design compressive load, so design compressive load should be greater than the external load and this design compressive load Pd can be find can be found from this formula that is Ae into fcd, where Ae is the effective sectional area effective sectional area which is defined in clause 7.3.2.

Unlike tension member in case of compression member effective sectional area will be the gross area in general, if generally we do not deduct the whole area because means considering that bolt or rivet whatever we provide are intact with the member. So the gross area will become the effective sectional area. And fcd is the design compressive stress of axially loaded compressive member. So we have to find out fcd the design compressive stress.

Now design compressive stress has been given in the code which is written as fy by gamma m0 by phi plus phi square minus lambda square whole to the power 0.5 or Chi into fy by gamma m0, this is basically stress reduction factor Chi. So stress reduction factor depends on the radius of gyration length and imperfection factor that means basically the slenderness ratio and imperfection factor, right. So and this has to be less than or equal to fy by gamma m0, that means this reduction factor cannot be become cannot become more than 1, okay.

So fcd value we can find out where phi can be calculated from this formula, phi is equal to 0.5 into 1 plus alpha into lambda minus 0.2 plus lambda square what is lambda lambda is root over fy by fcc or root over fy by fcc means pi square E by lambda square lambda means this radius of gyration KL by r. So fy into KL by r whole square by pi square E, here K is the effective length factor length factor to find out basically KL means the effective length and r is the radius of gyration, fy is the yield strength of the member and E is the modulus of elasticity of the material.

So from this I can find out the value of lambda, right and once I find out the value of lambda, I can find out the value of phi with the help of imperfection factor alpha. So once we can find out phi, we can find out the value of fcd by putting value of fy gamma m0 and lambda, right. So this is how one can find out the design compressive strength of a member.

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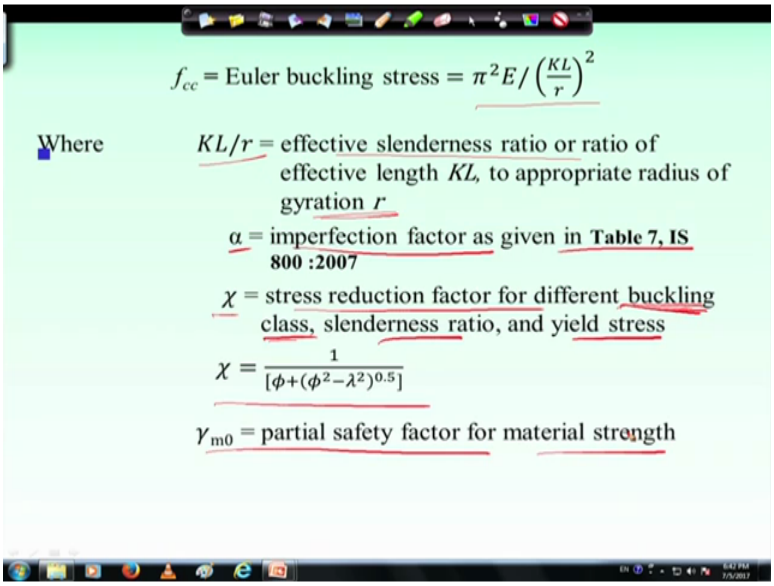

Here we have seen that fcc is basically Euler buckling stress which has been expressed as pi square E by KL by r square where KL by r is the effective slenderness ratio or ratio of effective length to appropriate radius of gyration, appropriate radius of gyration means out of two radius of gyration minimum one, right the minimum radius of gyration because about minimum radius of gyration the member will fail first. So strength of the member will be considered with respect to minimum radius of gyration.

Then alpha alpha is the imperfection factor as given in table 7 of IS 800:2007 and this Chi is the stress factor for different buckling class, slenderness ratio and yield stress, right. So three things have been taken into consider buckling class, slenderness ratio and yield stress, so these we can find out and gamma m0 is the partial safety factor for material strength, so gamma m0 is the partial safety factor for material strength, so this is how we can find out the value of fcd.

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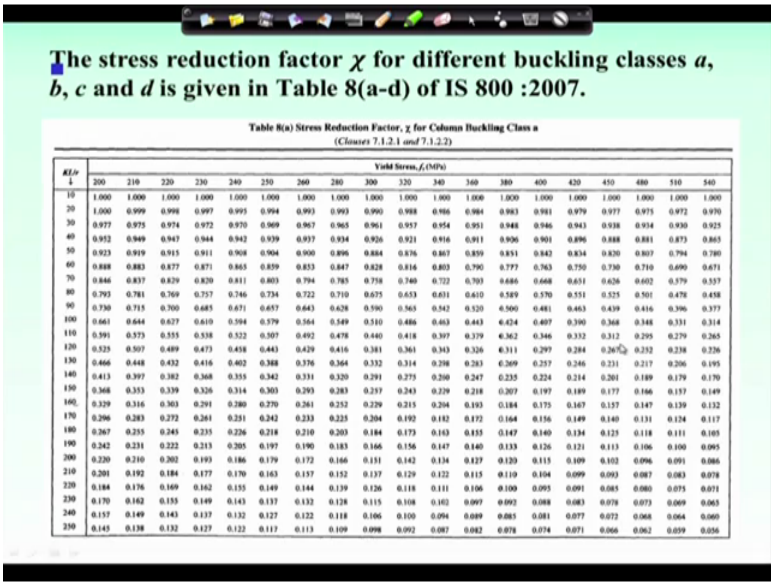

KL/r ↓	Yield Stress, f_y (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	1.000	0.999	0.998	0.997	0.995	0.994	0.993	0.993	0.990	0.988	0.986	0.984	0.983	0.981	0.979	0.977	0.975	0.972	0.970
30	0.977	0.975	0.974	0.972	0.970	0.969	0.967	0.965	0.961	0.957	0.954	0.951	0.948	0.946	0.943	0.938	0.934	0.930	0.925
40	0.952	0.949	0.947	0.944	0.942	0.939	0.937	0.934	0.926	0.921	0.916	0.911	0.906	0.901	0.896	0.888	0.881	0.873	0.865
50	0.923	0.919	0.915	0.911	0.908	0.904	0.900	0.896	0.884	0.876	0.867	0.859	0.851	0.842	0.834	0.820	0.807	0.794	0.780
60	0.888	0.883	0.877	0.871	0.865	0.859	0.853	0.847	0.828	0.816	0.803	0.790	0.777	0.763	0.750	0.730	0.710	0.690	0.671
70	0.846	0.837	0.829	0.820	0.811	0.803	0.794	0.785	0.758	0.740	0.722	0.703	0.686	0.668	0.651	0.626	0.602	0.579	0.557
80	0.793	0.781	0.769	0.757	0.746	0.734	0.722	0.710	0.675	0.653	0.631	0.610	0.589	0.570	0.551	0.525	0.501	0.478	0.458
90	0.730	0.715	0.700	0.685	0.671	0.657	0.643	0.628	0.590	0.565	0.542	0.520	0.500	0.481	0.463	0.439	0.416	0.396	0.377
100	0.661	0.644	0.627	0.610	0.594	0.579	0.564	0.549	0.510	0.486	0.463	0.443	0.424	0.407	0.390	0.368	0.348	0.331	0.314
110	0.591	0.573	0.555	0.538	0.522	0.507	0.492	0.478	0.440	0.418	0.397	0.379	0.362	0.346	0.332	0.312	0.295	0.279	0.265
120	0.525	0.507	0.489	0.473	0.458	0.443	0.429	0.416	0.381	0.361	0.343	0.326	0.311	0.297	0.284	0.267	0.252	0.238	0.226
130	0.466	0.448	0.432	0.416	0.402	0.388	0.376	0.364	0.332	0.314	0.298	0.283	0.269	0.257	0.246	0.231	0.217	0.206	0.195
140	0.413	0.397	0.382	0.368	0.355	0.342	0.331	0.320	0.291	0.275	0.260	0.247	0.235	0.224	0.214	0.201	0.189	0.179	0.170
150	0.368	0.353	0.339	0.326	0.314	0.303	0.293	0.283	0.257	0.243	0.229	0.218	0.207	0.197	0.189	0.177	0.166	0.157	0.149
160	0.329	0.316	0.303	0.291	0.280	0.270	0.261	0.252	0.229	0.215	0.204	0.193	0.184	0.175	0.167	0.157	0.147	0.139	0.132
170	0.296	0.283	0.272	0.261	0.251	0.242	0.233	0.225	0.204	0.192	0.182	0.172	0.164	0.156	0.149	0.140	0.131	0.124	0.117
180	0.267	0.255	0.245	0.235	0.226	0.218	0.210	0.203	0.184	0.173	0.163	0.155	0.147	0.140	0.134	0.125	0.118	0.111	0.105
190	0.242	0.231	0.222	0.213	0.205	0.197	0.190	0.183	0.166	0.156	0.147	0.140	0.133	0.126	0.121	0.113	0.106	0.100	0.095
200	0.220	0.210	0.202	0.193	0.186	0.179	0.172	0.166	0.151	0.142	0.134	0.127	0.120	0.115	0.109	0.102	0.096	0.091	0.086
210	0.201	0.192	0.184	0.177	0.170	0.163	0.157	0.152	0.137	0.129	0.122	0.115	0.110	0.104	0.099	0.093	0.087	0.083	0.078
220	0.184	0.176	0.169	0.162	0.155	0.149	0.144	0.139	0.126	0.118	0.111	0.106	0.100	0.095	0.091	0.085	0.080	0.075	0.071
230	0.170	0.162	0.155	0.149	0.143	0.137	0.132	0.128	0.115	0.108	0.102	0.097	0.092	0.088	0.083	0.078	0.073	0.069	0.065
240	0.157	0.149	0.143	0.137	0.132	0.127	0.122	0.118	0.106	0.100	0.094	0.089	0.085	0.081	0.077	0.072	0.068	0.064	0.060
250	0.145	0.138	0.132	0.127	0.122	0.117	0.113	0.109	0.098	0.092	0.087	0.082	0.078	0.074	0.071	0.066	0.062	0.059	0.056

Now this is a TDS process to find out the value of fcd, therefore in the IS code some values are given in a tabular form so that we do not have to calculate the entire things again and again.

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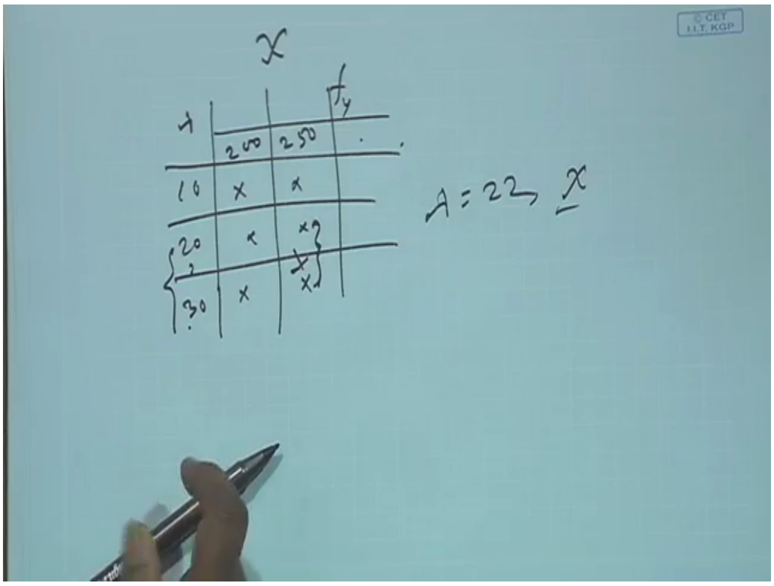

So if we see the table 8a to table 8d of IS 800:2007 this is given for different yield stress fy with different lambda, say 10, 20, 30 like this, the value of say this is 200 fy 200, say 250, so different type of values are given then the reduction factor value are given in different for different value of lambda and fy, right. So reduction factors are given. So if say for example if we have lambda in between 20 and 30 and fy as 250 then we can interpolate between these two to find out a particular value of reduction factor with respect to particular value of slenderness ratio.

Say for example if it is 22, say for lambda is equal to 22 we can interpolate between these two to find out the Chi value with respect to 22, right. So this table 8 to 8a to d one can find out the value of reduction factor according to the class buckling class a, b, c or d we can choose table 8a or 8b or 8c or 8d and we can find out the value.

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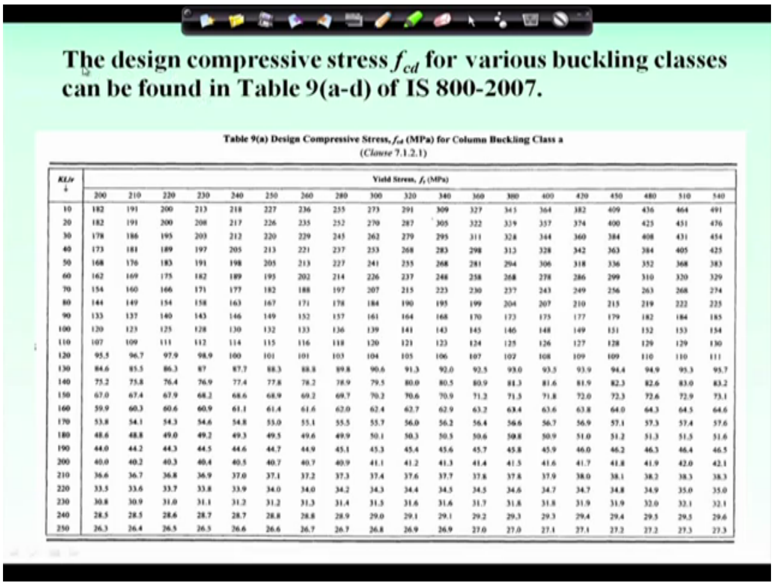

Table 9(a) Design Compressive Stress, f_{cd} (MPa) for Column Buckling Class a
(*Clause* 7.1.2.1)

KL/r ↓	Yield Stress, f_y (MPa)																		
	200	210	220	230	240	250	260	280	300	320	340	360	380	400	420	450	480	510	540
10	182	191	200	213	218	227	236	255	273	291	309	327	345	364	382	409	436	464	491
20	182	191	200	208	217	226	235	252	270	287	305	322	339	357	374	400	425	451	476
30	178	186	195	203	212	220	229	245	262	279	295	311	328	344	360	384	408	431	454
40	173	181	189	197	205	213	221	237	253	268	283	298	313	328	342	363	384	405	425
50	168	176	183	191	198	205	213	227	241	255	268	281	294	306	318	336	352	368	383
60	162	169	175	182	189	195	202	214	226	237	248	258	268	278	286	299	310	320	329
70	154	160	166	171	177	182	188	197	207	215	223	230	237	243	249	256	263	268	274
80	144	149	154	158	163	167	171	178	184	190	195	199	204	207	210	215	219	222	225
90	133	137	140	143	146	149	152	157	161	164	168	170	173	175	177	179	182	184	185
100	120	123	125	128	130	132	133	136	139	141	143	145	146	148	149	151	152	153	154
110	107	109	111	112	114	115	116	118	120	121	123	124	125	126	127	128	129	129	130
120	95.5	96.7	97.9	98.9	100	101	101	103	104	105	106	107	102	108	109	109	110	110	111
130	84.6	85.5	86.3	87	87.7	88.3	88.8	89.8	90.6	91.3	92.0	92.5	93.0	93.5	93.9	94.4	94.9	95.3	95.7
140	75.2	75.8	76.4	76.9	77.4	77.8	78.2	78.9	79.5	80.0	80.5	80.9	81.3	81.6	81.9	82.3	82.6	83.0	83.2
150	67.0	67.4	67.9	68.2	68.6	68.9	69.2	69.7	70.2	70.6	70.9	71.2	71.5	71.8	72.0	72.3	72.6	72.9	73.1
160	59.9	60.3	60.6	60.9	61.1	61.4	61.6	62.0	62.4	62.7	62.9	63.2	63.4	63.6	63.8	64.0	64.3	64.5	64.6
170	53.8	54.1	54.3	54.6	54.8	55.0	55.1	55.5	55.7	56.0	56.2	56.4	56.6	56.7	56.9	57.1	57.3	57.4	57.6
180	48.6	48.8	49.0	49.2	49.3	49.5	49.6	49.9	50.1	50.3	50.5	50.6	50.8	50.9	51.0	51.2	51.3	51.5	51.6
190	44.0	44.2	44.3	44.5	44.6	44.7	44.9	45.1	45.3	45.4	45.6	45.7	45.8	45.9	46.0	46.2	46.3	46.4	46.5
200	40.0	40.2	40.3	40.4	40.5	40.7	40.7	40.9	41.1	41.2	41.3	41.4	41.5	41.6	41.7	41.8	41.9	42.0	42.1
210	36.6	36.7	36.8	36.9	37.0	37.1	37.2	37.3	37.4	37.6	37.7	37.8	37.8	37.9	38.0	38.1	38.2	38.3	38.3
220	33.5	33.6	33.7	33.8	33.9	34.0	34.0	34.2	34.3	34.4	34.5	34.5	34.6	34.7	34.7	34.8	34.9	35.0	35.0
230	30.8	30.9	31.0	31.1	31.2	31.2	31.3	31.4	31.5	31.6	31.6	31.7	31.8	31.8	31.9	31.9	32.0	32.1	32.1
240	28.5	28.5	28.6	28.7	28.7	28.8	28.8	28.9	29.0	29.1	29.1	29.2	29.3	29.3	29.4	29.4	29.5	29.5	29.6
250	26.3	26.4	26.5	26.5	26.6	26.6	26.7	26.7	26.8	26.9	26.9	27.0	27.0	27.1	27.1	27.2	27.2	27.3	27.3

Similarly we can find out the design compressive stress in table 9 (a to d) for various buckling class.

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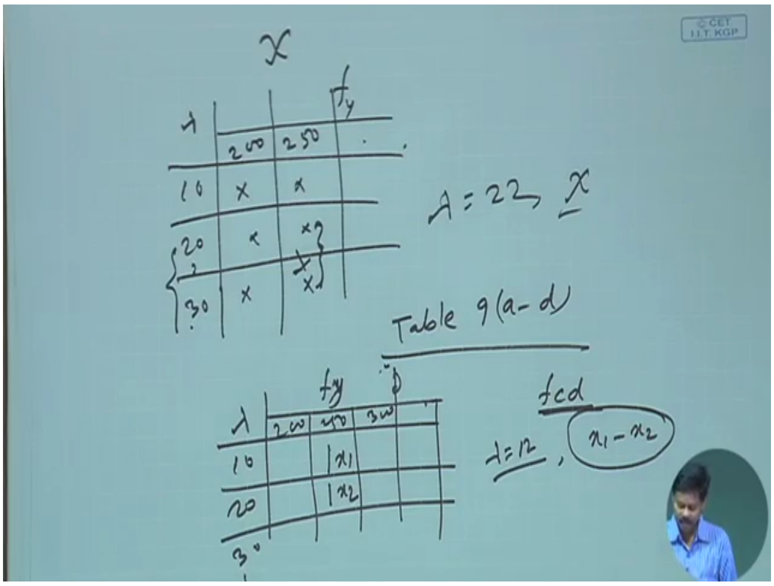

So in table 9 (a to d) we can see that for different value of lambda and for different value of fy yield stress, we can find out the value of fcd. Say for example say 10, 20, 30 like these lambdas are varying and fy is say 200, 250, 300 like this it is varying. So for a particular value of lambda we can find out the value of fy and then from the table 9 a, b, c or d according to the buckling class we can find out the value of fcd fcd value, say for example this is x1, this is x2 for 10 and 20.

Then for for lambda is equal to say 12, we can find out the value of fcd in between x1 and x2 means in between x1 and x2 we can find out the value of fcd by interpolating the values, right. So very quickly one can find out the fcd value by using table 9, table 9 have four tables a, b, c, d with respect to buckling class a, b, c, d.

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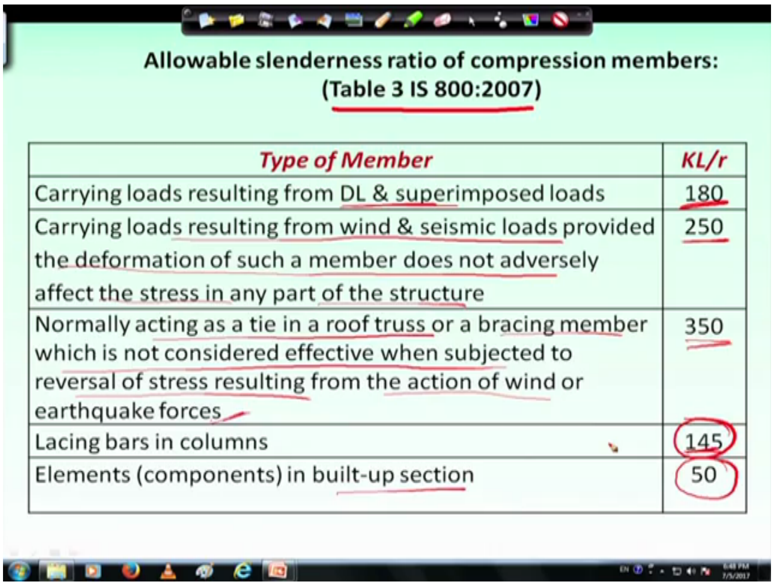

Now another thing we have to remember while designing the structure the structure means the compressive member that is the allowable slenderness ratio. So that has been defined at table 3 of IS 800:2007 the allowable slenderness ratio for compressive member that is like carrying loads resulting from dead load and superimposed load this the limiting value is 180 that means the effective slenderness ratio KL by r should not become more than 180 in case of dead load and live load or superimposed load.

When carrying loads resulting from wind and seismic loads provided the deformation of such a member does not adversely affect the stress in any part of the structure we can increase upto 250, so allowable slenderness ratio is 250 for such type of cases.

Now normally acting as a tie in a roof truss for a bracing member which is not considered effective when subjected to reversal of stress resulting from acting wind or earthquake forces that can be made as 350, so allowable slenderness ratio will become 350.

Similarly lacing bars in columns will be 145, when the built-up sections will be used then the lacing bars has to be designed, so in such cases the slenderness ratio will should not be more than 145.

And different elements or components in built-up section there it should be less than 50, so different components in built-up section the allowable slenderness ratio should not exceeds 50. So this is how we have to follow this codal provision while designing the member, right. So in todays lecture what we could see is that that one thing is the design column curve can be obtained from the Perry-Robertson formula which takes care the material properties, material strength which takes the slenderness ratio that means buckling and also the buckling class of the member that that means the configuration of the structure cross sections which effects as a local buckling.

So to take care these three effects the yielding, global buckling, and local buckling the formula has been derived, right and it is observed means it is observed from the literature that using such type of formula the behaviour of the compression members are similar to this formula whatever we are getting that means after numerous experimental verifications this formula has been has been adapted by our code and we can now use this formula for finding out the design strength of the compressive member and we can design accordingly.

So in next class we will see how to calculate the design strength of a compression member, we will how to calculate the design strength of a built-up compression member and then we will go for design of members compression members. So for todays lecture we will we will like to conclude here, thanks.