Course on Design of Steel Structures
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Lecture 24
Module 5
Steps for Design of Tension Members

Now I am going to discuss about certain steps which we should follow in case of design of tension member. So in last few lectures we have seen that how to calculate the design strength of the tension member and we have seen that tension member may fail due to its gross yielding, it may fail due to rapture of the net section, also it may fail due to block shear. So these three aspects we have to see as well as one another thing we have to see remember that is the slenderness ratio means radius of (())(1:01) and its allowable slenderness ratio.

The member which we are going to consider whether it is exceeding its limiting value or not that is necessary from serviceability criteria point of view. Therefore these four aspects we have to keep in mind while designing the things. So if we can develop methodology methodology means the steps that what are the steps we will follow whether we first calculate the slenderness ratio and we will try to find out the section or we will calculate the design strength due to block shear, then we will find out the section that we have to decide, right.

So in today's lecture I will give an overview of the steps to be followed and then I will come to the some flow chart that how if I write a program then how flow chart can be developed and how algorithm we can develop at our own, so that we can make a program and we can make it useful we can make it useful in the sense that we have seen that design calculation Tds we have to calculate lot of things, lot of complicated expressions are there.

So when we are going to design means it is a repetitive process repetitive process means we can start with certain angle section or certain other section but that may fail or may be overdesigned. So we may have to reiterate again, right. So doing all the things for every member it is Tds job. So if we can develop a program at our own in an customized manner then it will be useful and easier and helpful for us for designing a tension member in an economic way and in a short time, right.

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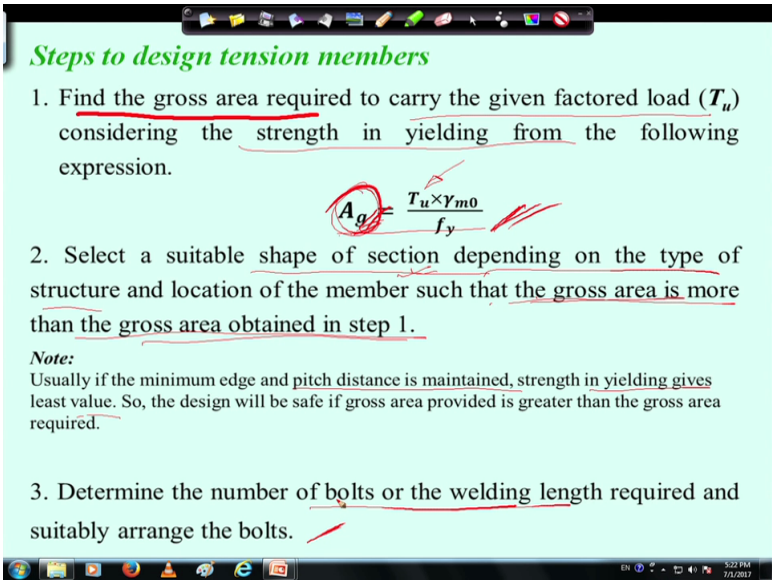

So if we come to the steps we will see that first step is we have to find out the gross area because the design because the load acting on the member is given that is Tu the ultimate load means the factor load that is given if the factor load is given then how do I decide the member, right. For a particular member if some factor load is given then how to start that can be started with the use of gross yielding of the section from that we can find out a approximate area because in our experience we have seen you can see in the previous example also we have seen that the least strength comes generally due to yielding.

So first we will try with yielding, we will try to find out the gross area then we will choose a section and then we will go for other sent criteria we will see whether it is fulfilling the criteria of not if it is not fulfilling then we have to go for higher section otherwise we can make use of it, right.

So first we will find out the gross area to carry given factor load Tu considering the strength in yielding from the following expression that is we know Tu is the means Tdg is the Agfy by gamma m0. So from that equation I can write that Ag is equal to Tu into gamma m0 by fy, right here Tu is the factor load that load coming in the member with certain factor.

Then from this Ag the gross area we can find out the suitable shape of section means first we have to design whether we are going for angle section, or channel section, or some other section, right. So depending on the shape of section we will go to the IS handbook and then we will find out what is the gross area available for a particular section, right.

So first we will find out the shape of the section whether it is I section, or channel section, or angle section then we will find out what should be the section size, right. So that section size can be found from this gross area if we know the gross area then we will go to corresponding area of that angle section or other section and then we will choose a section whose gross area is slightly more than the gross area obtained in step 1, right.

So member what we will be choosing its gross area will be more than the gross area obtained in step 1, because it has to satisfy this criteria, right and I mentioned already that usually if minimum edge and pitch distance is maintained, strength in yielding gives least value, right. So design will be safe if gross area provided is greater than the gross area required so here gross area required is this and we will provide slightly higher gross area and accordingly we will choose a particular section depending on the requirement, right.

Then what we will do one section is chosen section is chosen means two things we are choosing one is shape and its size, shape means whether it is angle section or channel section, or some built up section this is one thing and then size what should be the size, size of the section should be in such a way its area should be more than this area required area, required gross area, right.

And then we can find out the number of bolts or the welding length required and we can arrange the bolts.

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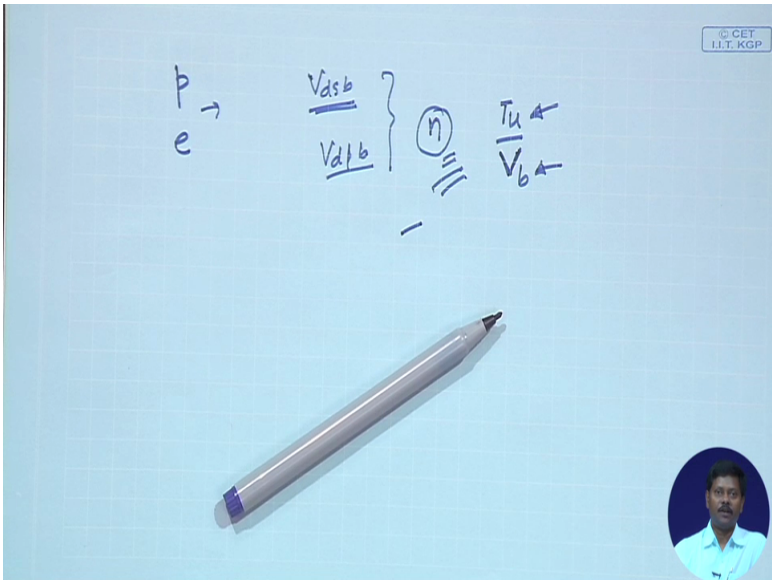

So what we will do next that we can find out a particular bolt means we can choose a diameter of bolt and then we can find out the pitch, edge distance, right and then we can find

out what is the shear strength of this bolt Vdsb shear strength of the bolt, then bearing strength of the bolt Vdpb, right.

So from this we can find out the bolt strength and then we can go to find the number of bolt required, right and this number of bolt we can find out from the total load coming that Tu by the shear strength, ok. So shear strength oh sorry strength of the bolt so say Vb, so if Vb is the strength of the bolt and Tu is the factor load then I can find out the number of bolt if we are going to use bolt connection.

And if we are going to use weld connection then also we have to find out the weld length assuming size of the weld, we can assume certain size of the weld depending on the plate thickness or angle thickness we can assume certain size of the weld and according to the size of the weld we can find out the strength depending on the material properties of the weld we are using. And then we can find out the length required to (())(9:21) that much tensile load that is Tu, ok.

So in second step what we can do sorry in third step what we can do we can find out the number of bolts and its positions that means how we are going to make it whether it is chain bolting or zig-zag bolting, so those things we will see and what will be its pitch distance, what will be edge distance, so all these things we will fix or if we go for weld connection what will be the weld length distribution in top and bottom and what will be the size of weld, what will be the length of weld so everything will be decided, right.

So in step three we have to do that because if we do not do that we will not be able to calculate Anc value and Ago value, net area of the connected leg and gross area of the outstanding length also we cannot find out the shear lag width unless we know shear lag width we cannot find out the factor beta then we cannot find out the strength due to rapture that is Tdn, also later we cannot find out the block shear strength.

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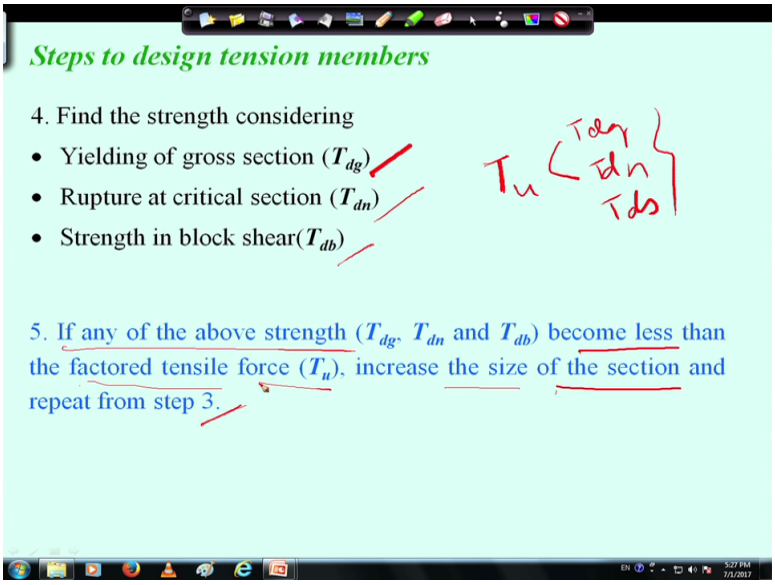

So to find those things we have to make detail of the connections, right. So once we do that in step 3 we can go further to step 4 that is in step 4 we can find out the yielding of the gross section that means Tdg, then rapture at critical section we can calculate this also, then strength in block shear, right. So these three we will consider and we have to see the Tu value the load acting on the member the tensile load that should be less than these three, this Tdg, Tdn, and Tdb, ok this has to be less.

That means so it has to be less if it is not less then what we will do we have to increase the size of the section, right. So if any of the above strength become less than the factored tensile force so so if if any of the strength become less than the factored shear force Tu then we have to increase the size of the section, right if it is more than the Tu then find that means if design strength is more than the applied load then it is fine otherwise we have to increase the size of the section and we have to repeat 3 step 3 we have to repeat, that means step 3 we will do again and again we will go for step 4, right.

So what we could see here that we have to find out the yielding of gross section, rapture of critical section and strength in block shear and these three strength should be greater than the Tu otherwise we have to increase the section size and we have to repeat the steps so that this this criteria is fulfilled.

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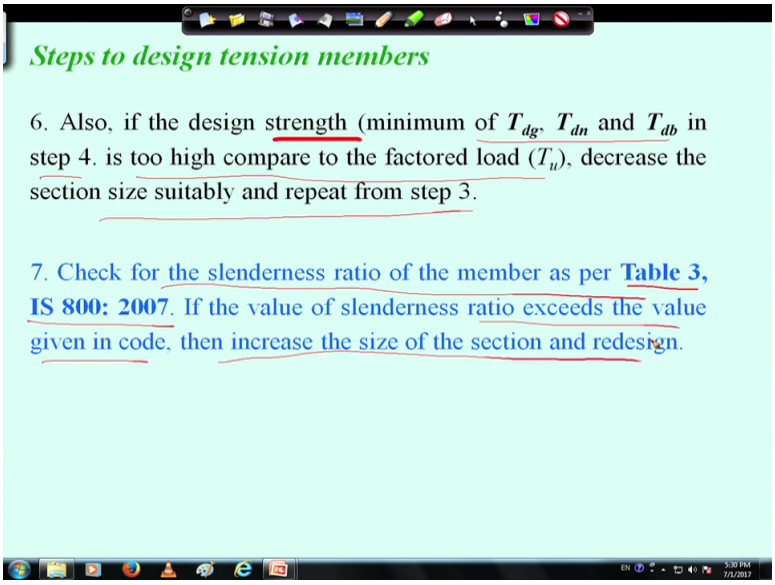

Next what we can do in step 6, that if we see the if the design strength that means minimum of these three in step 4, is too high compare to factored load then also we can decrease the section size suitably and repeat from step 3. That means if we see the design strength is quite higher than the applied load applied load means the Tu the axial tension if the design strength is quite high design strength means least of Tdg, Tdn and Tdb that is the design strength, if design strength is quite high then the Tu value that applied load then it will be a conservative design that means it will be uneconomic whatever section is required we have consider bigger section.

So what we can do we have to means we can go with this one or if we make if we want to make economic design then we have to reduce section size and again we have to follow from step 3, right.

And once it is over we can check the slenderness ratio of the member and the limiting value is given in table 3 of IS: 800-2007. Now if the value of slenderness ratio exceeds the value of given in the code, then this is not ok that means what we have to do then we have to increase the size of the section and redesign redesign means again we have to go to step 3 and we have to check all the things, right. So these are the steps which we have to follow for designing a tension member.

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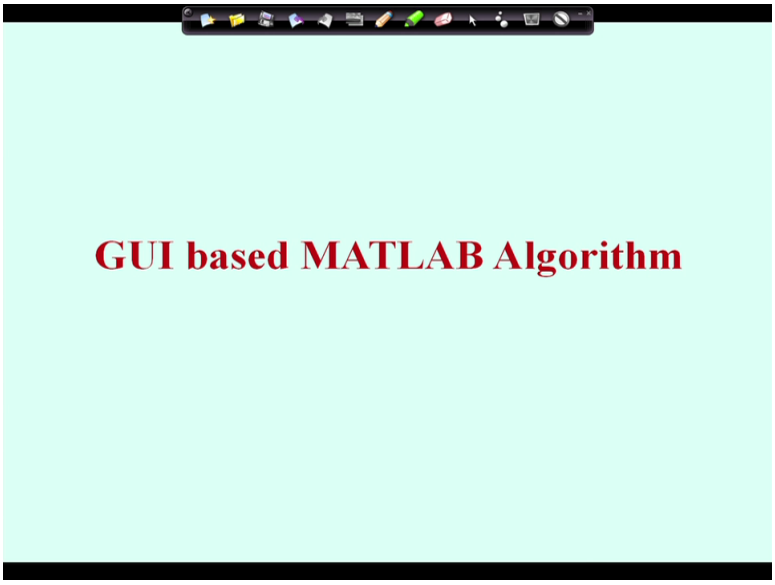

Next I will show uhh the flow chart diagram of the of the developed algorithm and I will show some screenshot of the developed code and one program I will run and I will show how the things are means outputs are coming and how we can make it useful, right. So it has been developed in MATLAB program and also it is graphical user interface based program, so as it is GUI based so it will be user friendly means user can easily make useful of this program and they can find out the intended section due to a particular load.

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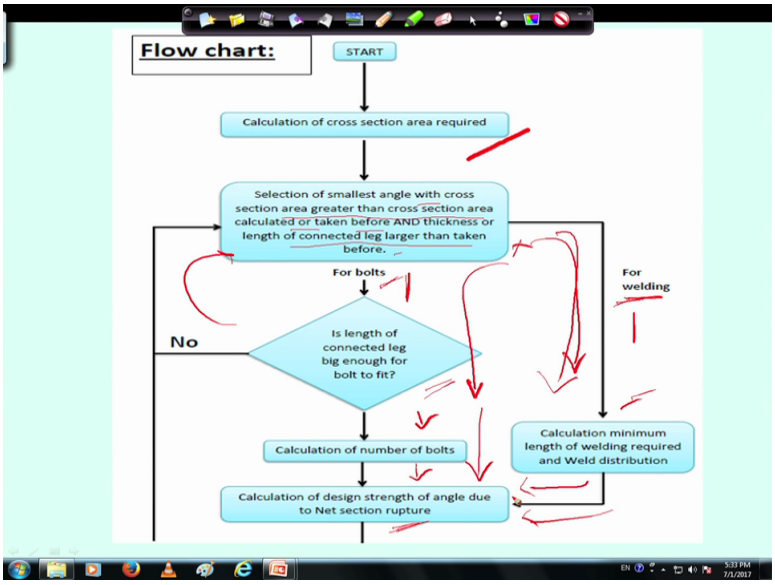

So in flow chart if we see the flow of the program will be like this this is basically based on the steps whatever I have discussed in earlier slides that is first what we will do is the calculation of cross section require that is from the gross yielding we can find out what is the

gross area require that is Ag once that is find out then what we can do we can decide means we can we have to decide whether we are going for bolt connection or weld connection.

So from gross area we can find out the smallest angle with cross section area greater than the cross section area calculated or taken before and thickness of length of connected leg larger than taken before, ok.

So as per the requirement with there we are going for bolt connections or for weld connection the program will flow accordingly if we go for (weld) bolt connection then we have to see whether length connected leg is bigger enough to fit the bolt if not then we have to go and we have to again increase the section size otherwise we can go for calculation of number of bolt, ok.

So after that we will go for calculation of design strength of angle due to net section rapture. So (net) rapture of net section we can calculate the design strength in other way also we can start with welding. So from that we can find out the minimum weld length require and weld distribution also we have to do then we will find out the rapture strength. That means once the section is selected either we will go for weld connections or we will go for bolt connections accordingly number of bolts and its distribution can be decided and then rapture strength can be calculated or if we use weld connection then also we can distribute the requirement of weld length properly and then we can find out rapture strength.

So as per the necessity we will follow the path, that means when we will right the program we will right in such a way that as per the choice of the user it will flow the path.

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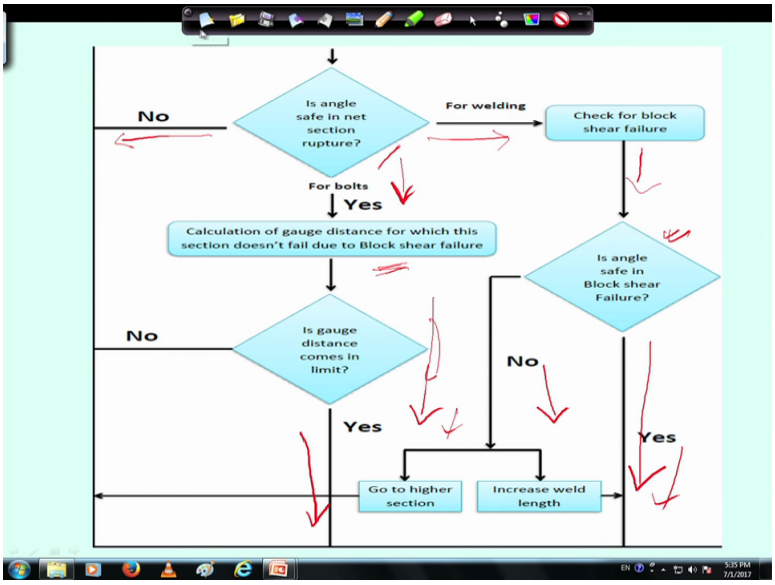

Next is we will calculate that is angle safe in next section of rapture that means the rapture strength we calculated in earlier step. Now if rapture strength is less than the applied force applied tensile force then we have to go to the earlier step to increase the section size, right. If it is not less than we will go for either welding or bolting as we have decided, that means if it is bolt then what we will do that we will find out the gauge distance and other things to find out the block shear so we will calculate the block shear.

And then if block shear due to block shear it is going to fail then what we can do we can change the gauge distance and we can redesign it, right means without changing the size of the section otherwise if it is not going to fail then we will go next step. Similarly here also in case of welding we check for block shear then if angle is safe then fine if not then either we will increase the length of the weld and then we will recheck or we will go for higher section whatever we feel we can do and if it is safe then we will go to next step next step means for bolt case also we will go to next step, for weld also we can go to next step.

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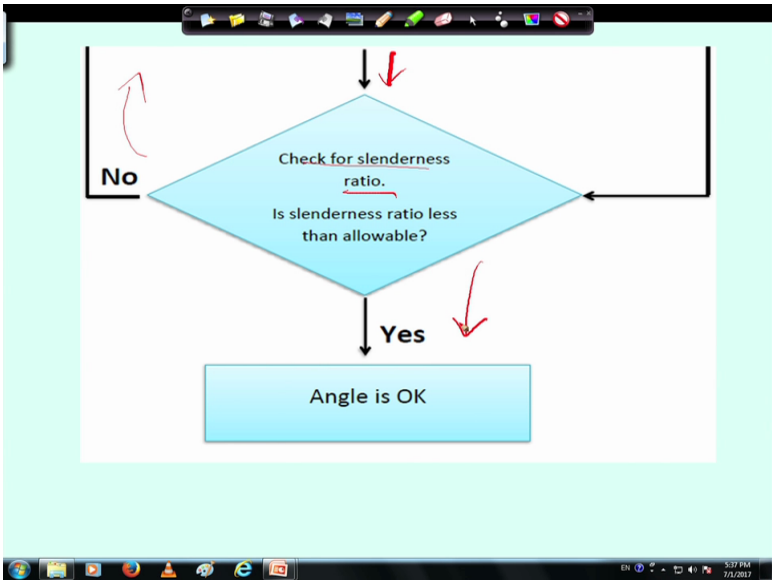

So in next step so what we have seen that the strength due to block shear, strength due to rapture is more than the the applied load, if it is so then it has come to this step, if it is no then it has gone to the earlier step to increase the section size, so once it is over the strength calculation is over we will go for check for slenderness ratio. So the slenderness ratio limit we know from the codal provisions and if the slenderness ratio is less than the allowable then it is fine if it is no then we have to go for increase of the section size, so that the slenderness ratio is becoming more, right.

And if slenderness ratio is less than allowable then we can say that angle is ok. So in this way one can flow its program so that he can write the program and find out the intended calculations.

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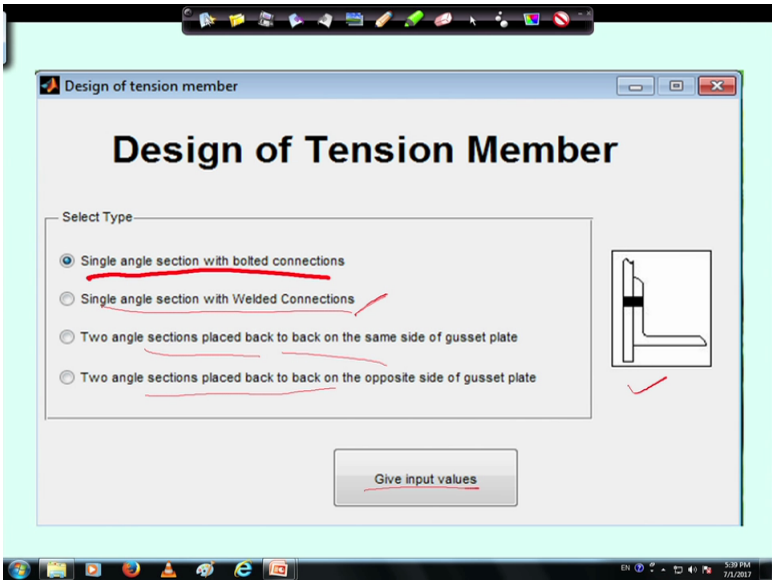

Now I will show some snapshot of the developed program as I told that develop program was done using MATLAB and in MATLAB you have options so this programs were developed by some of my students during summer summer intensive course. So in fact you can develop in other way means according to your requirement in the industry or in your case, so you can decide what should be the GUI and what are the options you want, right. Here we have given certain options like if you see option is that one is single angle section with bolt connections and single angle section with weld connections that means according to our option chosen we can find out the design calculation, so one is the single angle section with bolt connections or single angle section with weld connections.

Another option is two angle sections placed back to back on the same side of gusset plate, right and two angle sections placed back to back on the opposite side of gusset plate. So these are four options at that time we have considered you can choose any other type also like here only we have considered the angle sections, you can consider channel sections and you can find out its design strength also, you can consider any other sections also as you wish, just for demonstration purpose we have used this and then once you choose a particular type then you click on this give input values. So once if you click then you can go to next one, right.

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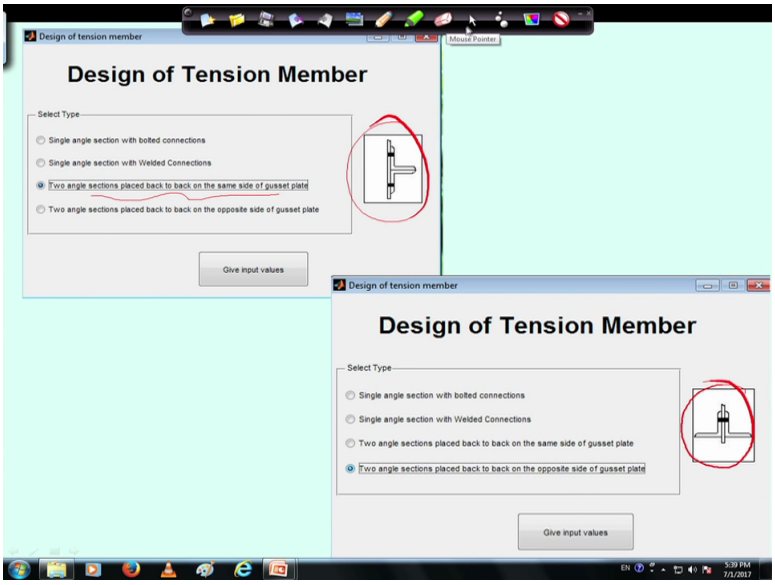

So here another snapshots I have shown that is if you choose this one that is that is if you choose two angle sections placed back to back, so it will be like this on the same side of gusset plate. Again if the angle sections are chosen on the opposite side of gusset plate it will be like this. So for different options different pictures have been given, so that the user can understand properly.

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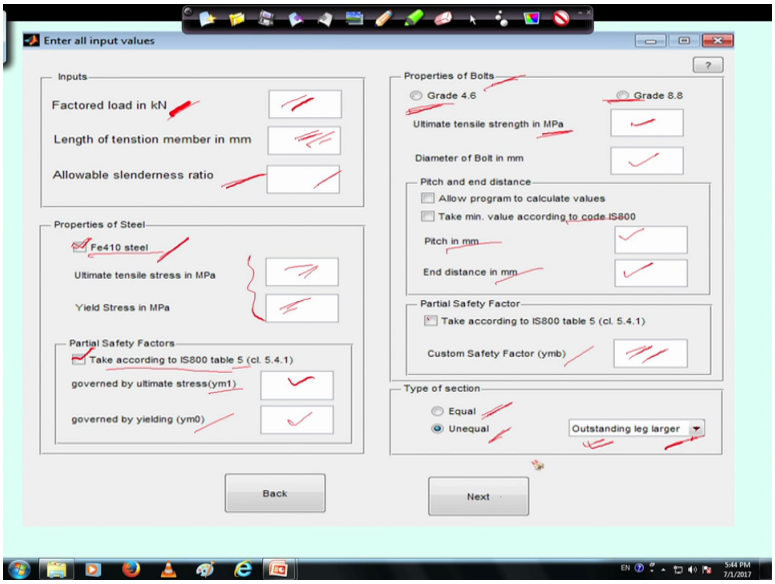

Now when we go next we can see that different inputs are asked by the program, one is the factor load in kilonewton, ok so you have to provide certain factor load, right. Then length of the tension member that is effective length effective length also you have to consider and you have to put the allowable slenderness ratio that is available in code. So allowable slenderness

ratio in particular case what is the allowable slenderness ratio that (())(25:37) also enter by the user, right. So these three inputs you have to give, one is the factor load and then effective length and also the allowable slenderness ratio, right.

So next the properties of steel we have to enter, properties of steel means what type of what grade of steel we are going to use what grade of steel means you can use that ultimate tensile stress that is fu, what is the value of fu in MPa and yield stress in MPa, right. So these two we have to enter or what we can do if we check this box if we make a tick to this box then automatically it will take the ultimate tensile strength value of Fe410 grade of steel. So one automatic value is given otherwise if you want other type of properties you can enter this.

Then again partial safety factor partial safety factor can be chosen as per the IS code in table 5 whatever given if we choose this then partial safety factor can be obtained automatically otherwise we can provide our own partial safety factor gamma m1 and gamma m0 is here, in place of 1.25 and 1.1 we can provide other partial safety factor also, right. So to make it generalize it has been made.

Next is the properties of bolt, if bolt connections are there then these these things will come, if it is not bolt connection then this screen will not come, right. So properties of bolt either we can use 4.6 grade bolt or 8.8 grade bolt these are means if you can choose this radio button then automatically its properties will be taken, otherwise we have to provide the tensile strength in MPa (())(27:39) that option is also available, right.

Then diameter of bolt you have to choose a particular diameter of bolt which you are going to use and then you can provide the pitch distance and edge distance pitch, distance and edge distance can be taken different way that is either you can provide the pitch distance means user can make definition of means make some value of pitch distance and edge distance or it can allow the program to calculate the values or means that is P is equal to 2.5d and 1.5d, right as per IS code it can take.

Then partial safety factor gamma mb of the bolt, partial safety factor also as per table 5 you can choose or you can customize means in place of gamma mb 1.25 you can provide some other value also, ok that is also possible. Then as we have chosen angle section because this program are developed only for angle section, so in case of angle section we have to define whether it is equal angle or unequal angle. If equal angle fine otherwise if it is unequal angle then you have two options that outstanding leg will be larger or outstanding leg will be

smaller because which leg is being connected depending on that its shear lag width will be calculated and other things also will be calculated accordingly that is why you have to give input to the program here that outstanding leg is larger or smaller and then you can go to next, ok.

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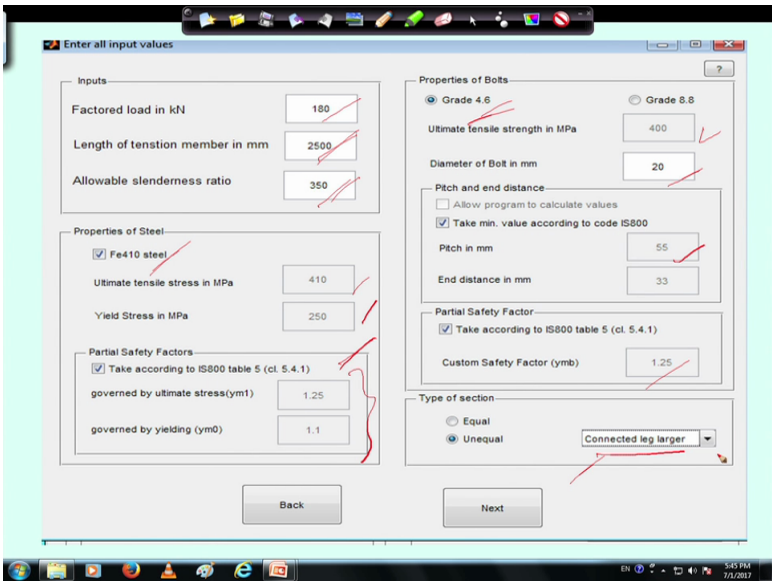

So after putting the value you can go to next so in next you can see that some values have been put here like factor load 180 kilonewton we have given, effective length we have given 2500 in millimeter, allowable stress we have given. Then we have check the that we have used the Fe410 grade steel, so it has come accordingly means ultimate tensile stress and yield stress has come accordingly.

And partial safety factor also has been consider as per the IS code and 4.6 grade bolt has been consider, so accordingly the ultimate tensile strength has been obtained. Then diameter of bolt then as per IS code we have consider pitch value. So in this way we have consider the input values, right like here we have told that connected leg larger, so connected leg is larger we have considered, right. So once these inputs are given you can go back to means you can go to next ok.

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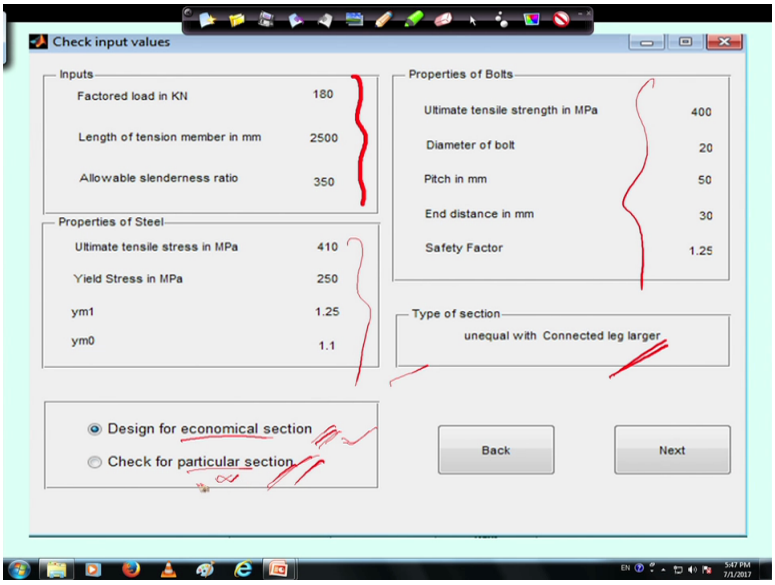

If you put next so all the data whatever we have put is giving here, ok all the data. Also so data means that what are the load and length, so partial safety factor and stresses, bolt properties, so everything is given and section is means which one is going to be connected larger leg or smaller leg, ok. So these are already given.

Now another option we have to tell that design for economical section or check for a particular section that means if you tell that check for a particular section then you have to give a particular section size say 90 by 60 by 6, if you give that then it will means program will tell you whether this section is safe or not, ok. And if you say design for economic section then the program will start with the minimum one and it will go on increasing then it will give you the just the section size which was which is going to pass, that means the minimum section size which is safe that will be given, which is called economic section.

So the beauty of this program is you can find out a economic section and you do not have to do manual calculations means n number of iterations you do not have to go program will do automatically and accordingly you can find out the most suitable section in terms of economy, ok. Or if a particular sections you have to provide you do not have other option you have you should you have to know only only that particular section which is available whether it is safe or not, that also can be done by giving this option, right.

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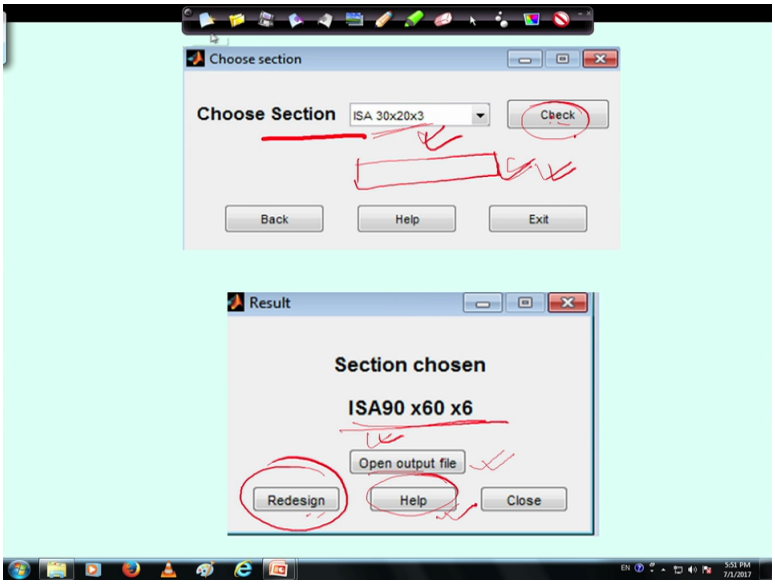

So according to the requirement either you can choose a section, right then if you click on this check then it will tell you that whether it is ok or not, means when you are giving a particular section and if you are putting a check means you can click in check then it will give you a dialogue of check that section is safe or section is unsafe, ok if it is unsafe again you can click another section then you can try that whether it is you check if it is ok fine, if it is not ok then you can go for again next one.

So by this way you can check for particular section and we can find out, right and you see here in drop box different sections are given as available in the IS code as SP6 as available in the SP6 we have made in database means all the properties of the say angle sections or channel sections are fit in database so all the things will come if you select a particular section is all properties are as per the codal provisions or properties are stored that will be used in the program, right.

And if you say that economic section then it will find out the economic section particular economic section then again you may act means you may want to find out what is the intermediate calculation, right. So what are the calculations happen that can be found if you use this the open output file if you open output file then the number of iterations the what are the things have been done all outputs will be is written in the program, means in the output file so all outputs will be displayed there, right in a file in a word file. So in word file you can get the output and you can check manually or means one or two you can check to get confidence that program is ok, right.

And also help file is there where if you click you will get the theory whatever has been used how it has been used all the things it has been made and if you are not satisfied with this, then you can go to again redesign means if you go to redesign then the earlier page will show and you have to change the design parameter, if you change the design parameter, then again if you redo then you can find out the new sections and you can make it.

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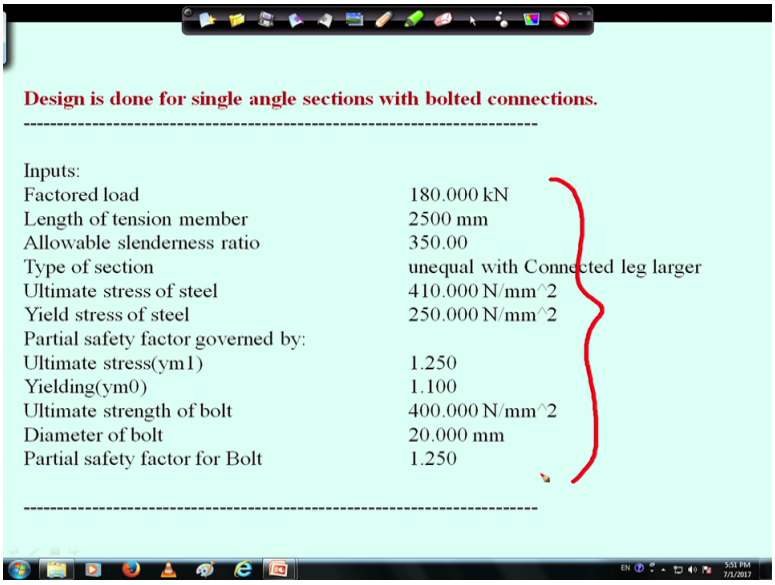

So this is a sample input and output if you see this we have done in the program, these are the (output) means input we have taken if you remember the screen we used this as input, right. So after providing this input one can get the output.

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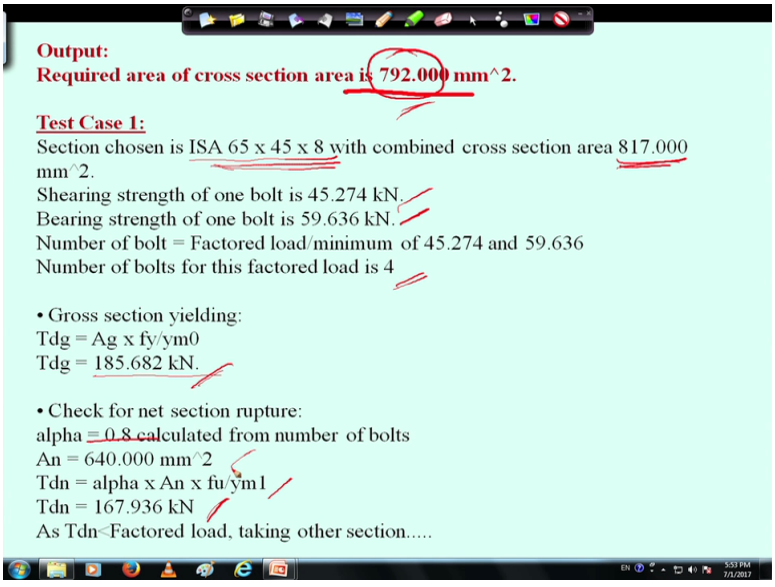

Output means so step by step this intermediate calculations should be shown like required area of the section as per the applied load that has been given, then it has started with this the section 65 by 45 by 8, so whose sectional area is 817 millimeter square and if you (remember) if you see we want this one and we have just given 817 that means just next to this value, right. So what computer has that means the algorithm has done that it has searched the value which are more than 792 section, ok. So according to that it could find that ISA 65 by 45 by 8 is coming immediately above this 792 millimeter square.

Then it has calculated the shearing strength and bearing strength of the bolt and then number of bolt also it could find out, right and then the gross yielding of the section it could find if you see 185 where 180 was the Tu value that applied load. Then check for net section in case of net section it has calculated that has number of bolts are 4, so alpha value has been taken as 0.8, so An value Tdn value has been calculated and it has seen that Tdn is 167 kilonewton that means it is less than the value given Tu that is 180. So as it is less than 180, so section is not safe that means it is going to next section, right.

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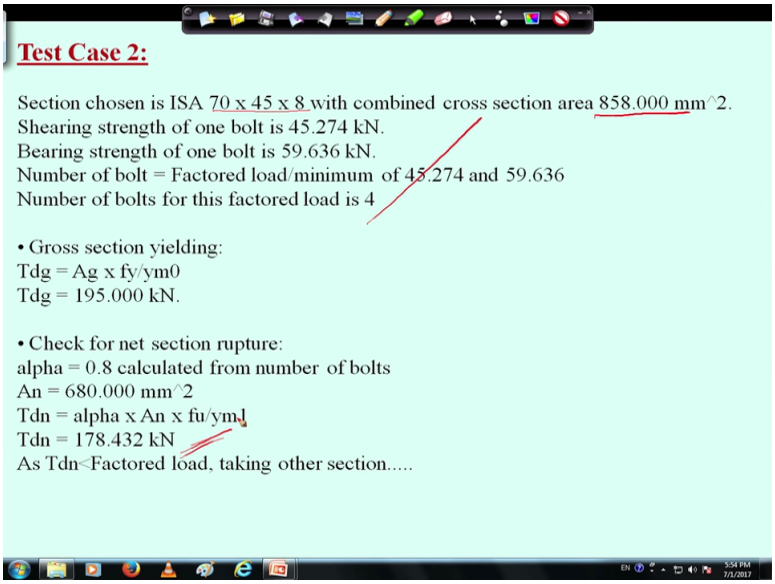

So it will go to next section next higher section is sorry next higher section is this one the 70 by 45 by 8 and its gross sectional area is 858 that means just for next higher section it has calculated all all the things and then it found that Tdn value is coming 178 kilonewton that means still it is not ok that means we have to go again next higher section, right.

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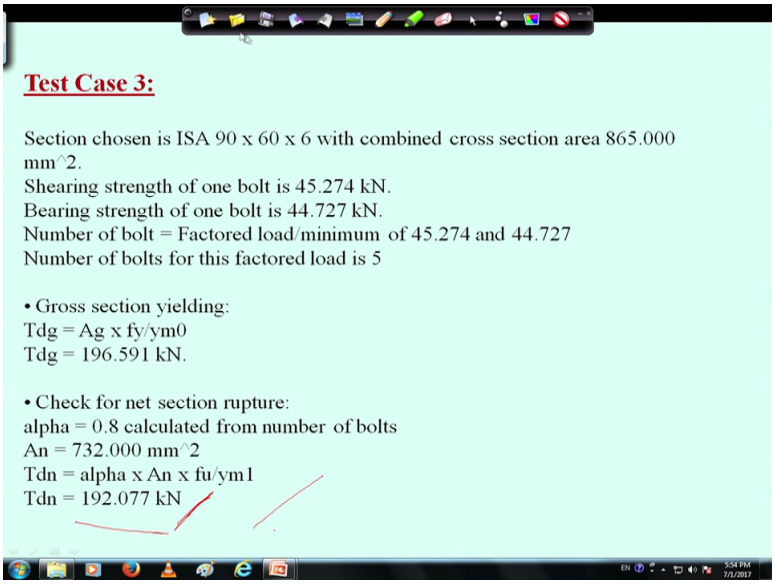

So for next higher section in test case 3 Tdn value is coming 192, which is more than 180 that means this time it is ok. So every time it is iterating all those calculations, repeating all those calculations and then finding the value, right. So in this case Tdn value it is getting 192, so what it can go it can go for next calculation that is Tdb block shear strength, ok.

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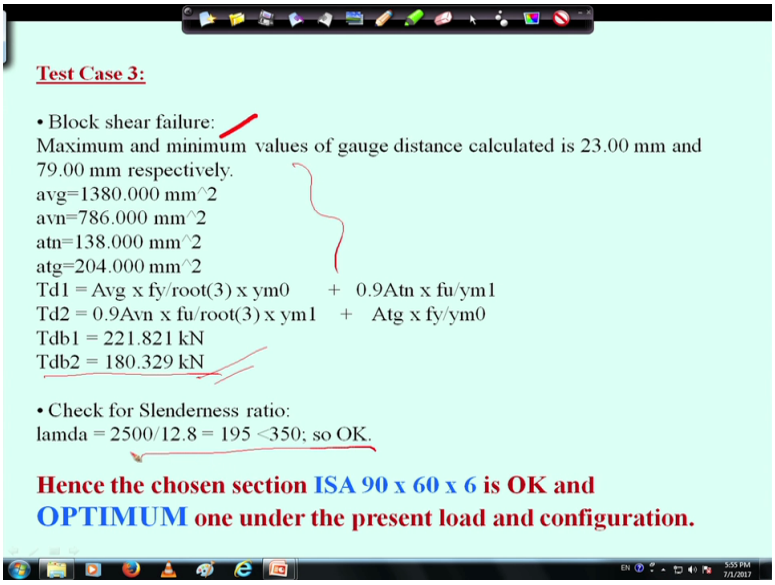

So block shear failure calculation should be done, so for block shear again Avg, Atg, Avn, Atn all these things should be calculated and then it is calculating the Tdb2 value is coming just 180, right so this is ok just 180.329, ok. That means from here we can see that the just minimum section which is required has been found, right and then slenderness ratio point of view also it is ok that means this is (ok) this section is safe, right. So it is the optimum

sections or economic section and under present load and configuration this is the best suitable sections we can tell, ok.

Now we can means we can imagine that if we have to do calculations of all manually it would take lot of time, right to get the economic sections because we do not know which section is going to be safe. So we have to try with different sections, so for so many repetitions it takes lot of time so that can be saved if once we can develop a algorithm, if once we can provide a program then means while writing a program it will take little time but once it is written and tested then n number of times we can use it without wasting any time and confidently we can make it useful, right.

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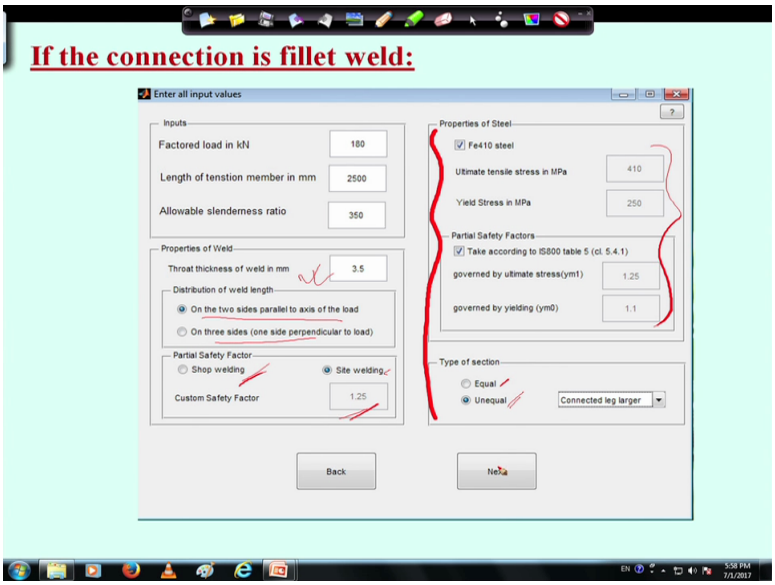

Now again I will show for fillet connection very quickly I will go through this that if we use fillet weld then in case of bolt these will come these properties will come, right like sorry in case of bolt in case of fillet weld that whether it is shop welding or site welding accordingly it can consider the partial safety factor then on two sides parallel to axis of the load or three sides that you have to decide accordingly this can be calculated, weld thickness you have to give and then again similar things that equal or unequal section and other properties of steel which earlier has been given same thing we can give. So accordingly all entries can be made through this GUI and we can make it useful.

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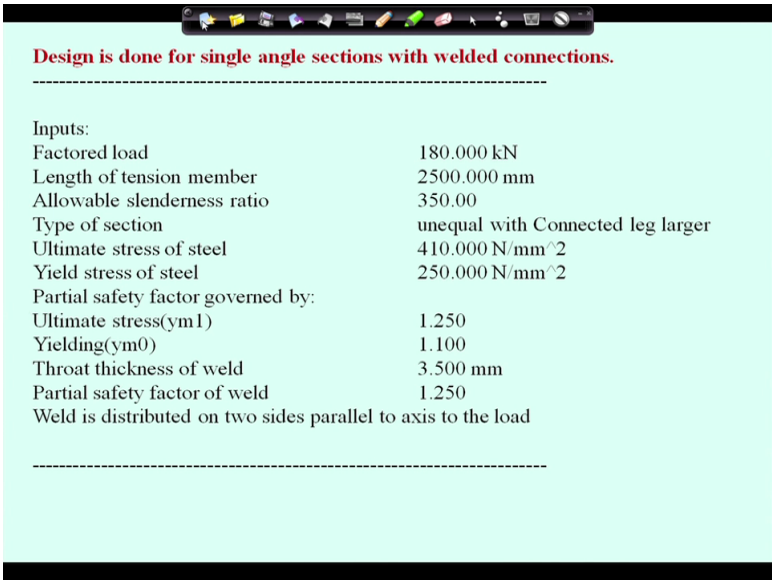

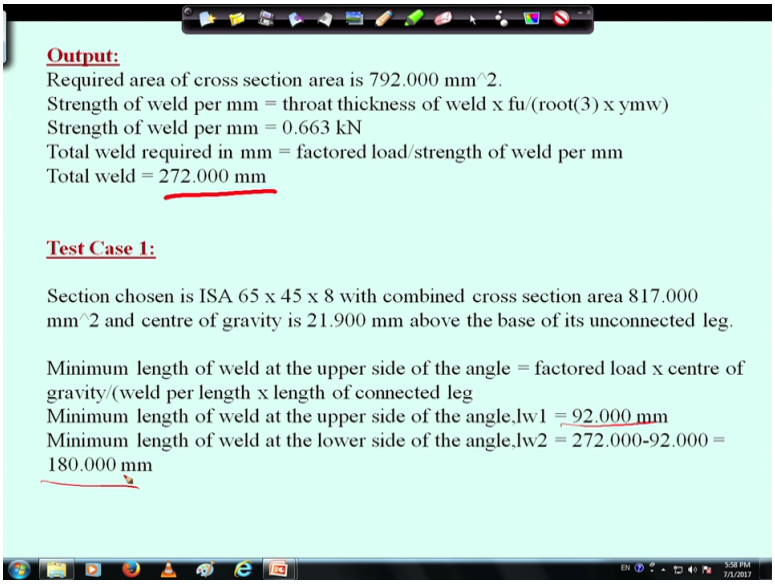

And then if we see for the same value whatever we have consider in case of bolt connections we have used same for weld connection then we can see that output is coming like this in test case 1 we could see that the total weld length is coming 272 millimeter and Lw1 and Lw2 we are getting this means weld length distribution that is necessary for calculating the weld strength, shear leg distance and other things, right.

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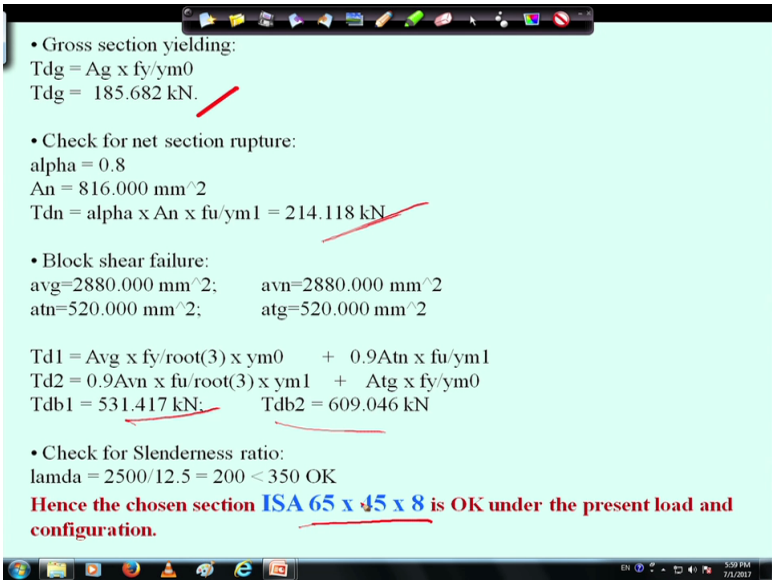

So once weld distribution is over we can find out Tdg value now in this case you can see Tdg value is coming ok and then Tdn value is also coming ok unlike bolt connections in case of bolt connection it was going to fail but in this case it is ok and Tdb value also we could see that Tdb value are also quite high, right. So here you see that in one iteration we could find out that the section 65 by 45 by 8 is ok under the present load and configuration, so this is how one can decide.

So in short what we can see that this is a sample algorithm and program we have developed and it was developed by my students during summer (intern) intensive and this program may have certain mistakes means we have to rectify that also however I have checked with details I could not find mistakes so however means when you will be writing program you do program as you feel means comfortable that means either you can write program only for bolt connection then separately only for weld connection, or a same program in which you will make bolt connection, weld connection together.

Similarly you can make the connections where angle (())(45:29) means two angles are placed back to back of the gusset plate or at the same side of the gusset plate. So either different programs you can make or in same program different functions you can made and you can make a single program, right and then as per your requirement and choice you can make useful means GUI means in the GUI you can provide certain inputs, ok and then from those input you can provide output of intermediate calculations so that the user can get confidence on the use of this and we can (remem) we can feel that whatever calculations are doing by the program is ok because manually also it is coming same.

So that options you have to give so that the user can whenever he feels doubtful he can check that means he can check a program and make sure that your program is correct, right. So once you make the program then means for example for tension member then you do not have to means waste more time for this once you have developed n number of times use this and every time you can use you can get, you can safe your time and you can get an economic sections, right.

So I will encourage participants or those who are listening this video to develop their own program whatever language they find comfortable that whether C, Fortran, or MATLAB or any other Python program whatever you feel you can develop and it may not be possible to make GUI but you can make in other way GUI may not be possible you enter the program in screen and find out the results so that way also one can make it, right and when you will be writing program it will be more clear to you how the programs are running, how the logics are going to be developed and how you are applying a logic one by one to satisfy the design criteria of all the things that will be clear, right. So with this I would like to conclude todays lecture, thank you.