Structural System in Architecture

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Lecture – 23
Analysis of Truss Part-2

Welcome to the NPTL or online certification course on Structural Systems in Architecture. This is module 5 and it is on Truss and Space Frame. Today we are in third lecture of this week; and topic is Analysis of Truss Part-2.

The concepts to be covered in this lecture are:

- Truss Framing System
- Classification of Truss System
- Numerical Analysis of Truss

The intended learning objectives of this particular lecture is to:

- Outline and classify of the framing system of Truss.
- Analyze force distribution in Truss due to geometrical patterns.

So far whatever we have discussed on Truss, all are about individual Truss. We have talked about geometrical formations of a Truss, what are the different parts of a Truss, and how to analyse an individual Truss. But you should know that one single Truss cannot serve the purpose; and we need a series of Truss, which may be of similar kind or may be different with changes in its geometry. Then we have to place those series of Truss one after another, maintaining some distance in between, and that distance is called as spacing of the Truss. So, the series of Truss is integrated as one structure to take care the whole roof of the building. All the Truss will be supported by some pillars or columns or by some other structural members like wall.

The series of Truss will be then connected by means of some horizontal connecting members called as purlins; and by virtue of the purlins the integrated system of Truss is generated. The purlins are always placed at the joints or the nodes of a Truss, in order to obtain smooth transferring of roof loads. So, the series of Truss, its span, spacing, and plan view is shown in Figure-1.

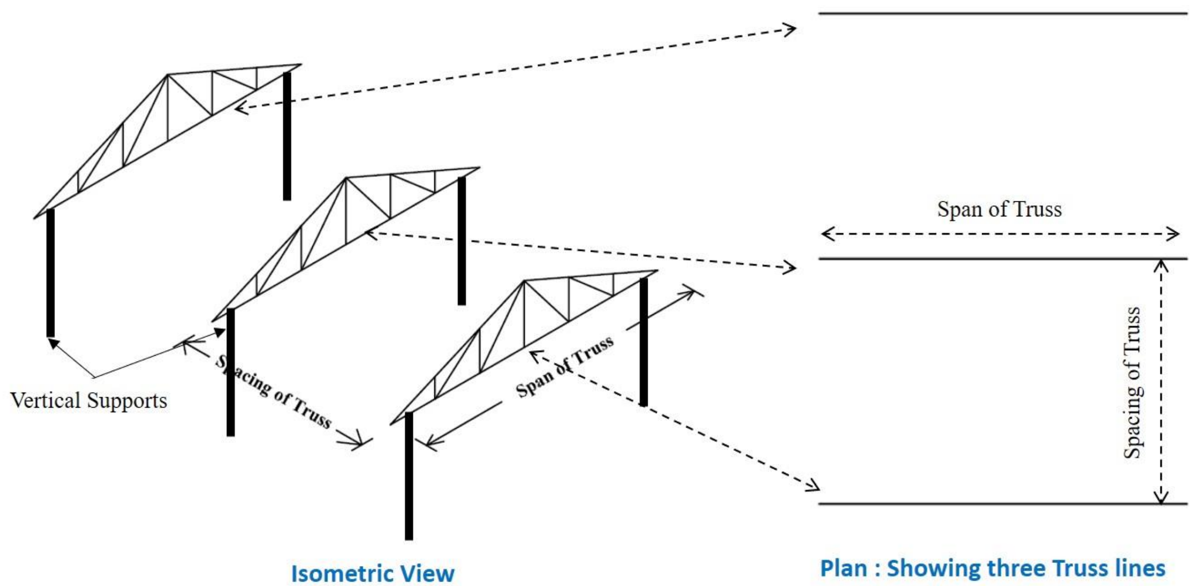

Figure 1 : series of Truss and its basic details

In the plan (in Figure-1, above) we can see three lines, they are the three Truss, separated by a unit of distance. So, we can see the spacing of Truss, span of Truss and the vertical supports.

Now, only these three units of Truss is not enough to hold the roof. As discussed, they must be united or tied together by some other structural members, and they are the purlins. So purlins are the connecting members between one Truss to another, and it is shown in blue color in Figure-2.

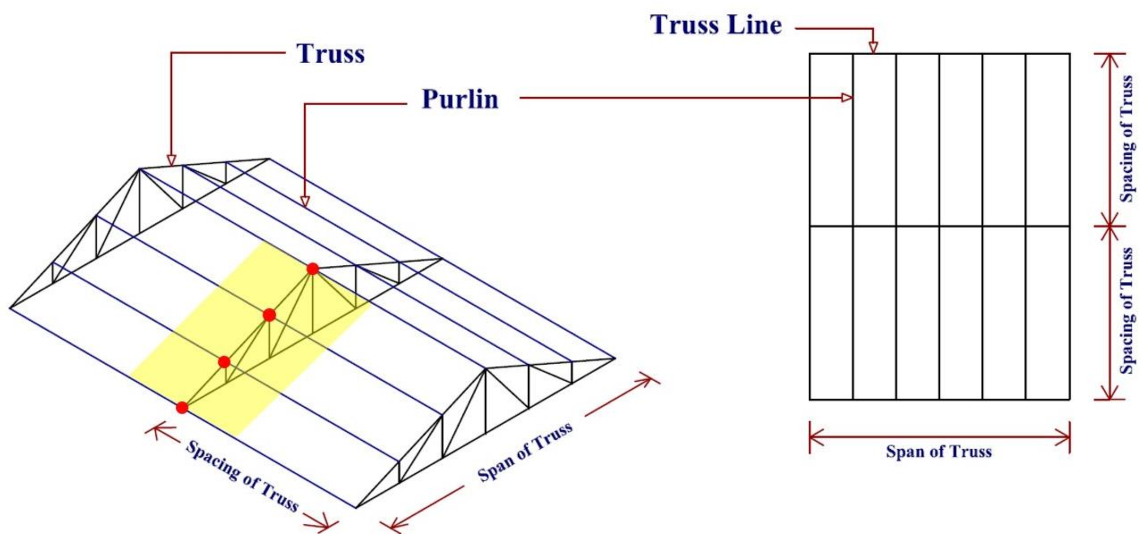

Figure 2 : three Truss connected by purlins

The purlins will create the surface to hold the roof covering; and there are various types of roof coverings available.

The Purlins will actually help in two ways; one, it will connect one Truss to another Truss in between the spacing and they will give an integrated Truss system; second, the purlins will transfer the roof load through nodes or joints of each individual Truss.

Let us assume there is roof covering, the yellow portion in Figure-2, left side image. The load of this roof covering is actually transmitted by the purlins to the particular Truss, through those four nodes shown in red dots in Figure-2. Then, we can find out total amount loads, the dead lode, live load, wind load etc. and we can also evaluate the load amount in each of these four joints of the Truss. We will discuss about load transfer mechanism of Truss in the next lecture. However, the plan of the Truss system with purlins is shown in Figure-2.

Sometimes, this type of Truss system only with the Truss and the purlins is fine. If the wind load is not much high, there is no much of span then, only the purlins can take care of the roof covering. However, if you expect a longer span or you expect very high wind load, like in situations of coastal areas, when you are near to the sea. As well as, sometimes there may be some other loads like infrastructural load like gantry girder or something like that. Then, only the linear purlins will not help. In such situations, you have to go for top diagonal bracings.

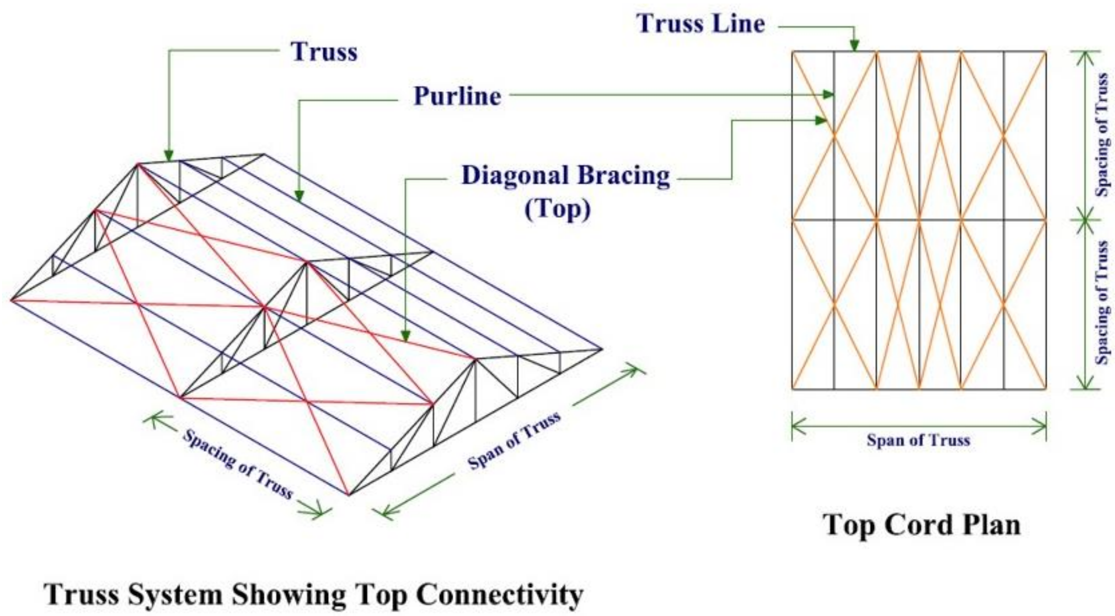

Figure 3 : diagonal bracings in a Truss system

In Figure-3, the diagonal bracings are shown in red color; connecting members diagonally from one Truss to another, and this should also connect through the nodal points only. So, in addition to the purlins we have to provide some diagonal bracing. How many bracings and of what type and size, we have to identify through some mathematical computations; for that we also have to know about the load distribution of the system. In the Figure-3, if you see the plan, it is called Top Chord Plan because whatever is shown over there, the purlins and the diagonal bracings, all are actually placed over the Top Chord or the two sloping portions of the Truss. Sometimes, this may be the suitable design, because, the combination of these diagonal bracings and purlins can hold the system good, under heavy wind load or for larger spans.

But, in some cases, the wind load may further high and you need much more robustness in your system. You need much more strong connectivity in your system to make it stable under those kinds of situations. Then we have to go for the next left out option, that is bottom chord.

In case of bottom chord, you can place the purlins in the bottom chord. They are not exactly the purlins, but we can call it as bottom chord horizontal members or bottom chord purlins. As well as, you can place some diagonal bracings in the bottom chord. If you do that, then you have to draw the bottom chord plan also, connecting the Truss, bottom chord purlins, and the bracings, just the way it was done for top chord. It is shown in Figure-4.

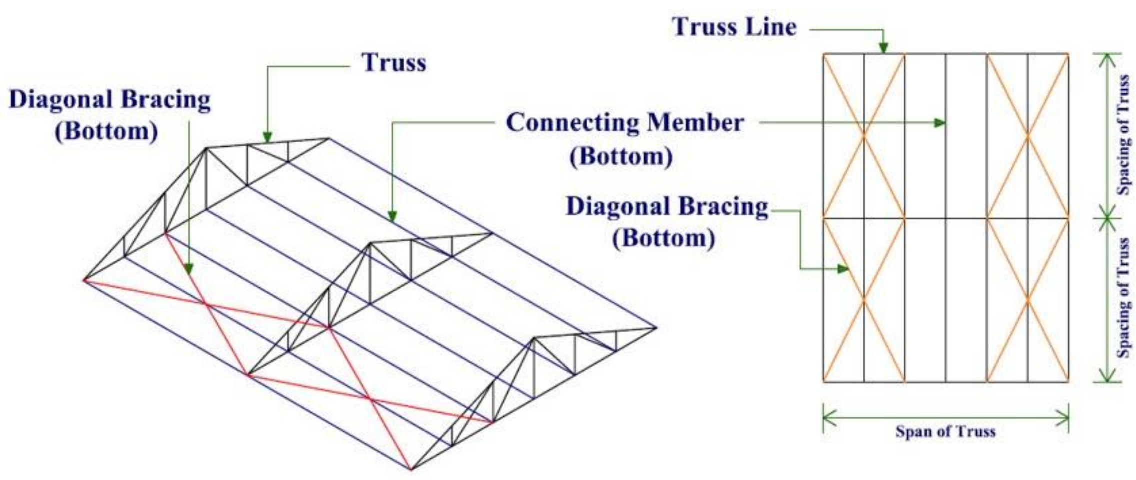

Figure 4 : bottom chord diagonal bracing

Finally, this will be the end of it, because now you will be not left with any other surfaces.

Further, if you still have the stability problem or something like that, then what you have to do is, you might have to change the pattern of the Truss. So, instead of this pattern you can go with some heavy type of Truss or you may decrease the spacing of the Truss to resolve the issue. Why spacing of the Truss? Because that will reduce the load on the individual Truss and it will result in better stability. Hence, number of Truss will increase in the length of the building, and definitely the load sharing will be reduced per Truss. So, this is about the Truss framing system.

We, use steel sections for Truss. Typically, there are three types of steel sections used. They are Light Sections, Heavy Sections and Built-up Sections, as shown in Figure-5.

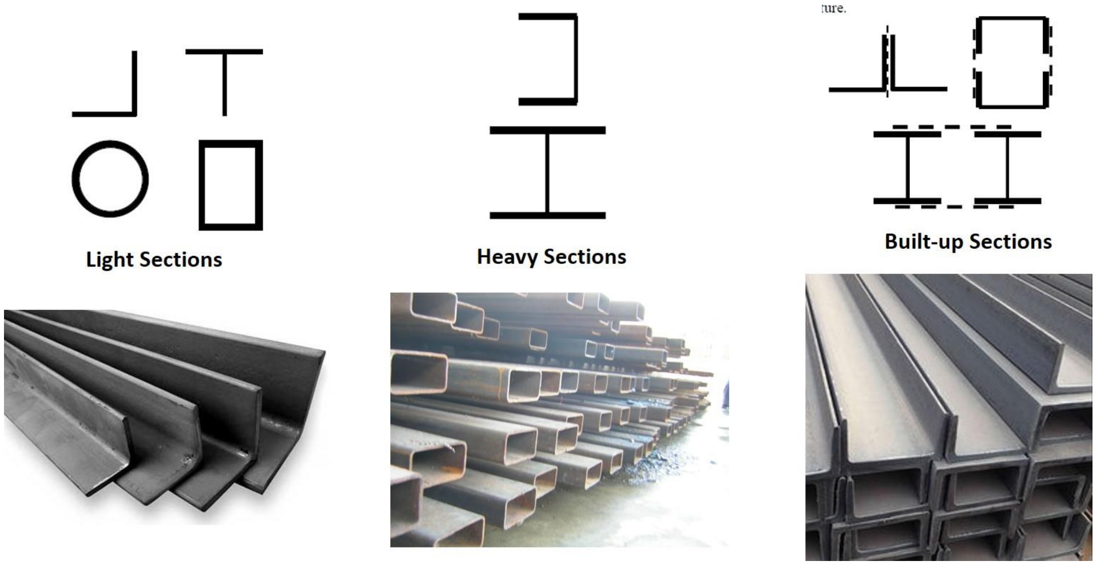

Figure 5 : types of sections used in Truss

What is the light section? The light sections are angle section, T section, circular pipes or the square hollow sections or square rectangular hollow sections, as shown in left-hand side image of Figure-5. The lower middle and lower right-hand side images in Figure-5 are rectangular hollow section and channel section respectively.

In case of the channel section it is a heavy section. Sometimes I sections can also be used as some of the members or you can use two channel sections and make it a box, which is called as the built-up section. So, we can have two angle sections to create the inverted T, you can actually make a box out of two channel sections, and we may go with a heavy section made up by two I section.

So, those are the typical built up sections that can be formed and we can have those sections as members of the Truss. The light sections are very popular. The designer tries to make or try to build the Truss with the help of this angle, T or the box sections, first they will try to make it with the angle and then the T and the box sections. The circular hollow pipes are also used for a lightweight Truss system. The built-up sections are used for auditoriums and similar structures. But the last one the heavy sections are used for structures like railway bridges.

Now, the classification of the Truss system. If you see the typical geometry of the Truss, the profiling of the total Truss, the purlins and diagonal bracings, and finally how the total form will look like, and then, again you come back to the individual Truss you can understand the system of the Truss. And the Truss system can be categorized into the three types. These Truss systems are for two-dimensional Truss system. For the 3-dimensional Truss system like the space frame system we have another category. In 2-dimensional Truss system, the first category is called the Flat Truss System. The Flat Truss System has further four sub-categories. The second one is called the Transmitted Flat Truss System; and it is having three subcategories. The third one is called Curved Truss System, which is having four subcategories. Detailed classification is given in Figure-6.

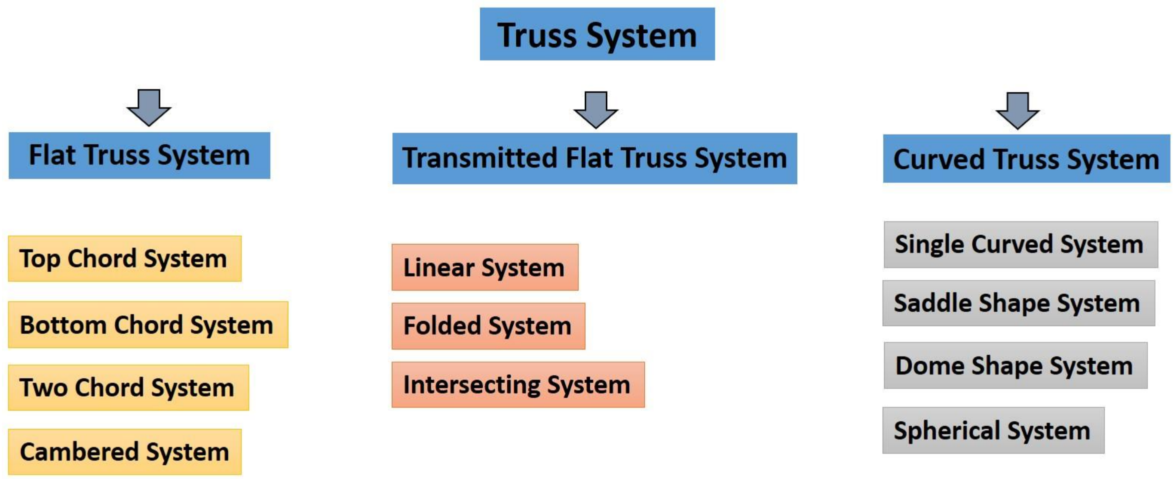

Figure 6 : classification of Truss system

Now, when you see the classification of Truss then first one is Flat. So, I understand that this Truss will have an inclined or the pitch member. The second one is the flat Truss system but it is transmitted form. It may be provided in a linear or maybe some angular transformation or with folds in a direction; so that is a transmitted Flat Truss System. The third one is clear from the name itself; that is curved Truss System.

Now, let us go into further details of these three types of Truss system.

Flat Truss System:

In Flat Truss System, first is Top Chord System. In this the bottom chord is flat and top chord is inclined or curved. The top chord is not flat; and it takes care of the roof covering, membrane or the profiling, whatever we provide. Refer Figure-7.

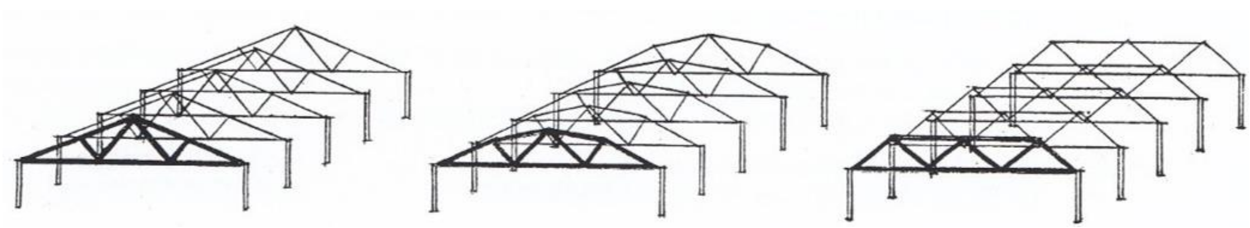

Figure 7 : Top Chord System

Second is Bottom Chord System. It is opposite to top chord system. Here, top chord member is flat and bottom chord members are inclined or curved. This is not much used in buildings. But have wide applications in bridges; most commonly, the middle and the right-hand size images in Figure-8.

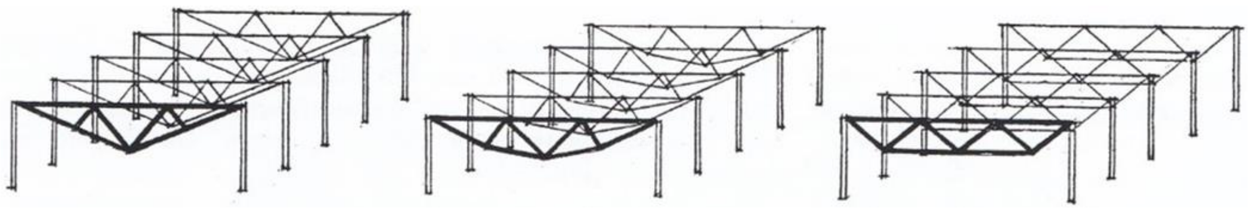

Figure 8 : Bottom Chord System

Then, the third one is the Two Chord System, where both the chords are the having non flat members or inclined members, as shown in Figure-9. These systems are used in the buildings particularly in the auditoriums, airports or any large span structure like galleries. This type of system is used to gain the advantage of wider spans in the buildings of structures. One of these systems will be discussed in the next lecture.

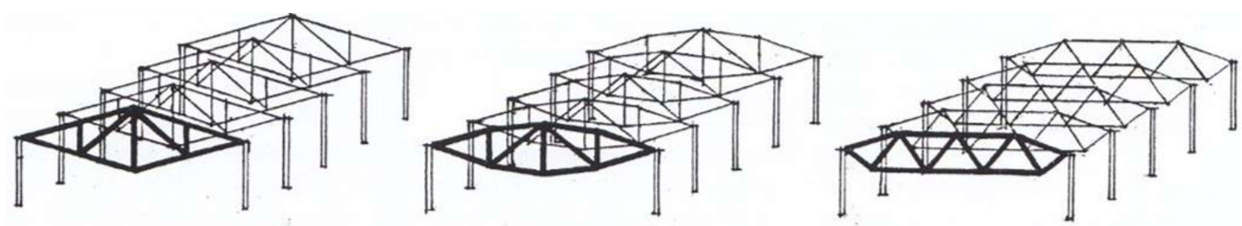

Figure 9 : Two Chord System

The fourth type is Cambered System. In this, top members are flat and non-flat both the type, but the bottom chord is elevated, the bottom chord is not flat. So that is called the Cambered System. Refer Figure-10.

Figure 10 : Cambered System

Transmitted Flat Truss System:

The next is Transmitted Flat Truss System. It has three subcategories, Linear System, Folded System and Intersecting System.

In linear system you can see that it is a system with a parallel chord or may be pitched, but it is linear. It is flows with a linear 2D plane. The same Truss can also be in zigzag or maybe any kind of a profile; but those are one after another and linear in order. Refer Figure-11.

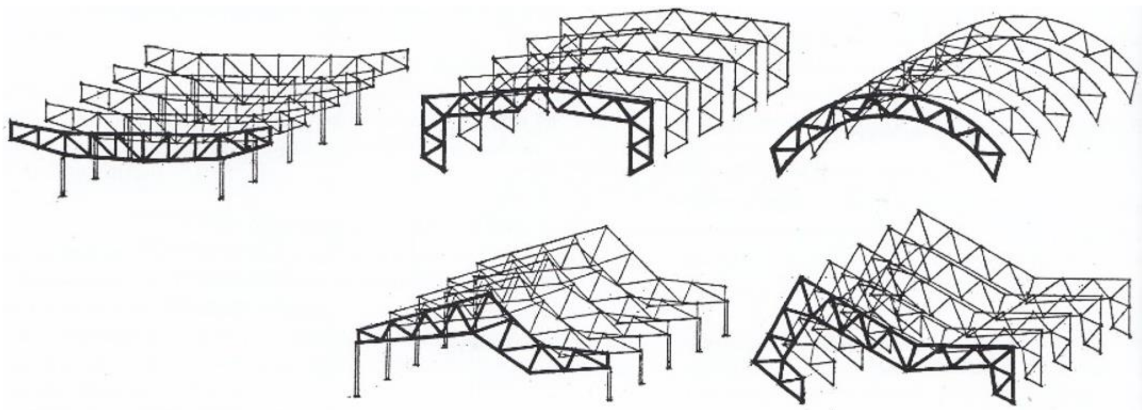

Figure 11 : Linear System

The next one is non-linear, but it is like a folded system. If you have one set of Truss and then another one set of Truss and another set of Truss, if it goes like that; then it is linear. But if it is intersecting, one with the next like shown in Figure-12, if it is intersecting in a line then it is a folded system.

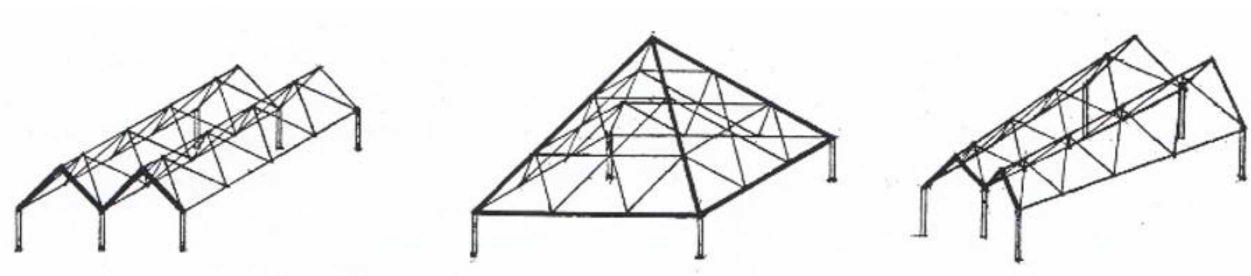

Figure 12 : Folded System

The third type under Transmitted Linear System is Intersecting System. It is intersecting in other way around. In first case that is in folded system the intersecting manner is in a line and in this case, the intersection of bodies; for example- one body intersects the another through its centre point, and that is the intersecting system of the Truss, refer Figure-13. All these linear folded or the intersecting Truss systems we use them for our built environment.

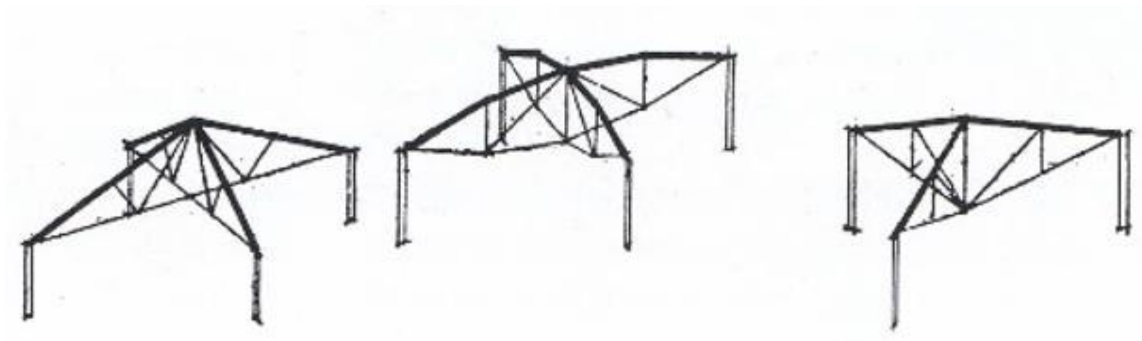

Figure 13 : Intersecting System

Curved Truss System:

The third type of Truss System is Curved Truss System. It has four subcategories. They are Single Curve, Saddle Curve, Dome Shape System and Spherical System. So, the details of these Saddle shape or Dome shape and Spherical shape, we will be discussed thoroughly in our sixth week, under different types of shell structures.

So first is Single Curve, then there is a Double curve, there is a Saddle shape, then Dome shape and Spherical kind of Truss systems can also be thought of. So, these comes under the category of the Curved Truss system.

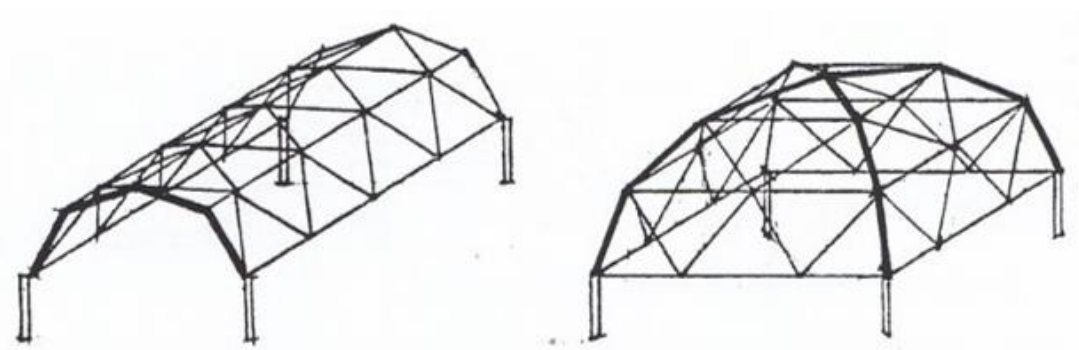

Figure 14 : Single Curved Truss System

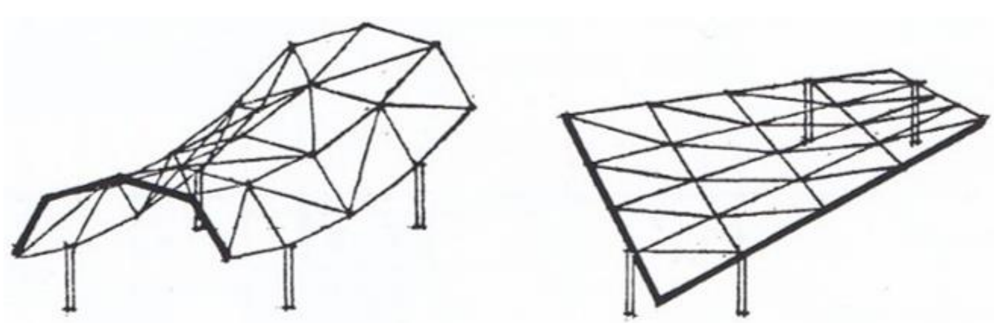

Figure 15 : Saddle Shape System

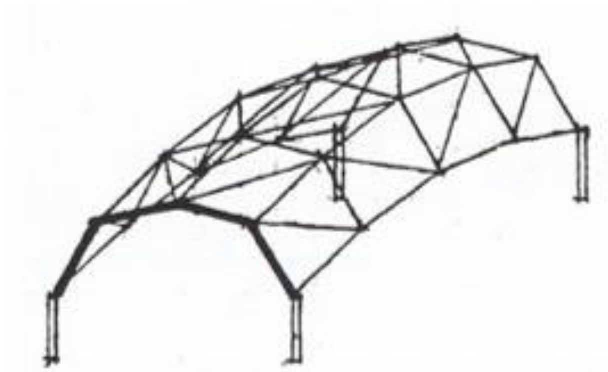

Figure 16 : Dome Shape System

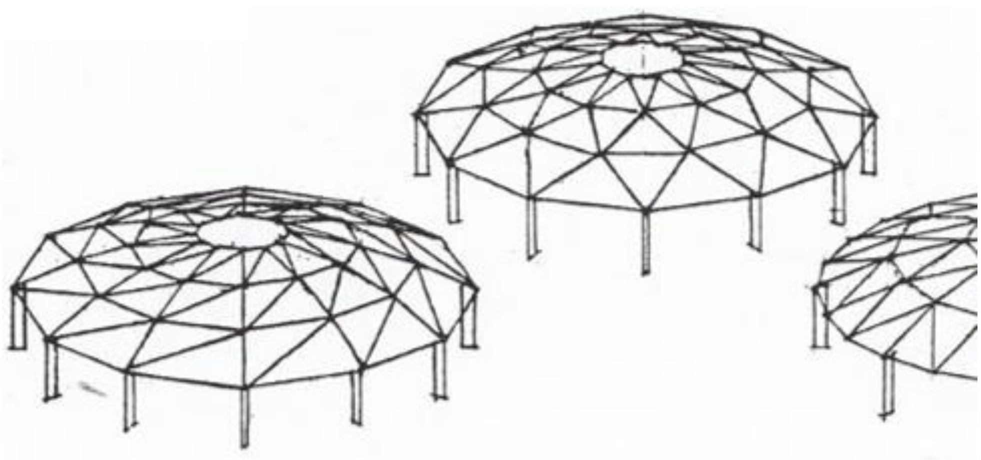

Figure 17 : Spherical System

Next, let us go to some numerical analysis of Truss. Here we want to see that, how the geometrical pattern of a Truss and also the support system will influence the internal forces or we can say the distribution of the forces in a Truss. From our earlier lecture we already know how to analyze a Truss by virtue of section method and joint method. Now, we will take 2 or 3 types of Truss and we will try to judge these 2 or 3 types of Truss and see how it behaves.

So, in the first case we are taking Truss-1 and Truss-2, Pratt Truss and Fan Truss respectively. Both are having span of 6 meters, and rise of 2 meters. The loads are also very similar, 50 KN in both the cases. Refer Figure-18.

Now, let us see which one behaves better or are they same in the nature?

Next, I have solved both the Truss by virtue of the joint method, and I found the forces and noted down in each respective member which is shown in Figure-19.

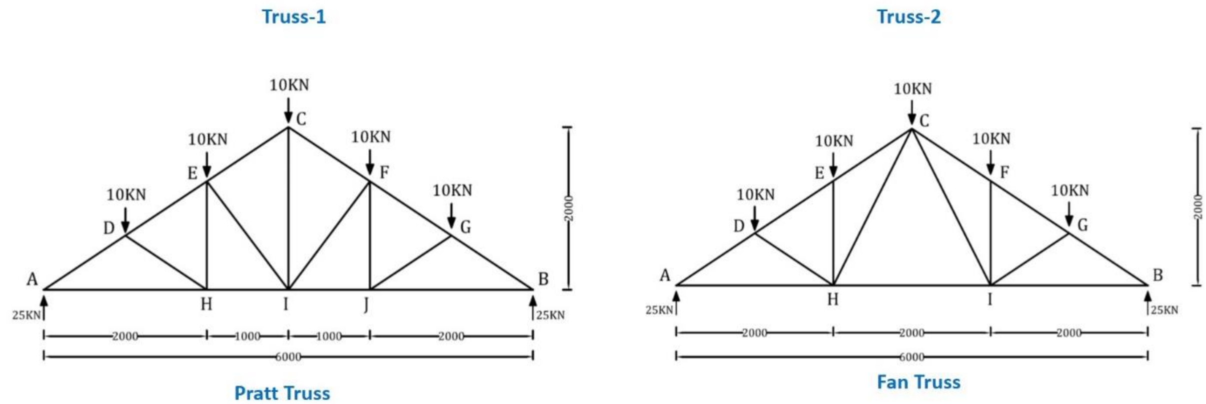

Figure 18 : two Truss for analysis

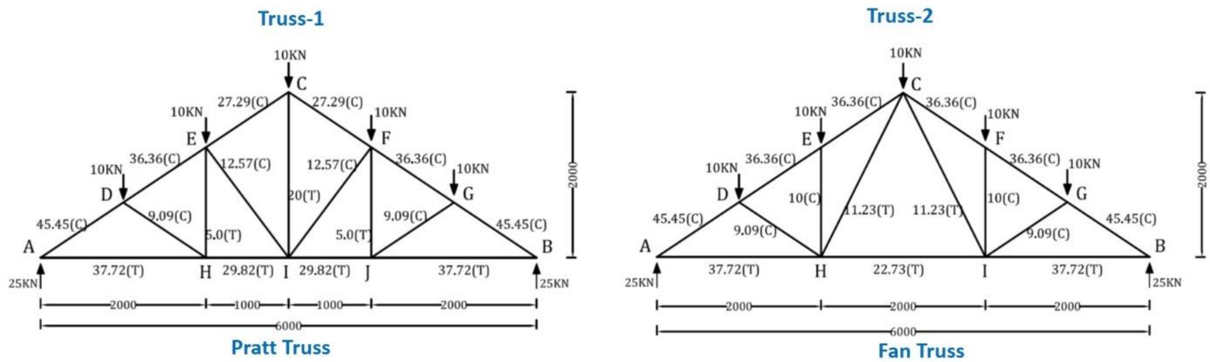

Figure 19 : two of the Truss with resolves forces of its members

Both the Truss are symmetrical, so the forces are also very much symmetrical. The two Truss looks very confusing with all the numbers. Therefore, I have redrawn these two figures with the help of color distinctions, where the tension members are shown in red and compression members are in purple color, as shown in Figure-20.

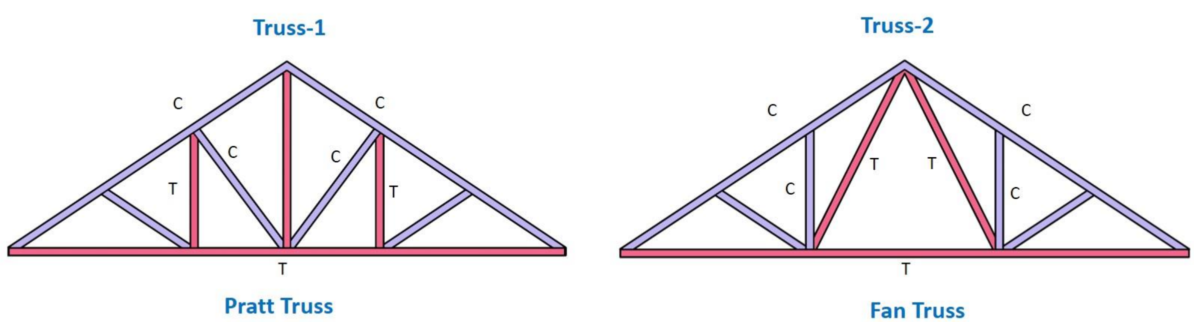

Figure 20 : tension and compression forces in the Truss

So, here you can see that, this Truss is also behaving like a beam, as you know if you put the load on the top to a beam, the beam bends and due to the bending of the beam the topmost portions comes under compression and the bottom part comes under the tension, and in Truss also it is similar. The compression and the tension are purely created by the topmost portion and the bottom most portion in both the Truss, which is completely similar behaviour to the beam. However, the internal members, the post or the struts behave differently. If you look at Figure-20, you will see the posts are mostly under tension, but in Fan Truss the two posts are under compression; their behavior changes. On the other hand, in Pratt Truss the struts are under compression but in Fan Truss they are under compression as well as under tension.

Here, one thing is very clear to us, that under the gravity load or downward load a Truss perfectly behaves like a beam; that means the topmost portion, the rafters are in compression and the tie beams are under tension; that is why it is called tie beam. But the internal members, the posts and the struts behave differently because of the change in geometry and orientation. See, there is no difference in the span, no difference in the rise, no difference in loading, the only difference is the orientation of the internal members and its geometry. The actual triangles or the bigger triangles or the outer profiles are same in both the Truss. The difference exists only in the orientation of internal members.

The nature of forces in the internal members are bit confusing, because some orientation take compression and sometimes the same post or strut of same height can take the tension.

Now, if we compare the Truss-1 and Truss-2 in a Tabular form then, we will see that they are mostly same. There is no much difference in between them. Refer Table-1.

Table 1 : comparison of Truss-1 and Truss-2

Truss-1		Length (m)	Force (KN)	C/T
Rafter	AD	1.2	45.45	C
	DE	1.2	36.36	C
	EC	1.2	27.29	C
	CF	1.2	27.29	C
	FG	1.2	36.36	C
	GB	1.2	45.45	C
Tie	AH	2	37.72	T
	HI	1	29.82	T
	IJ	1	29.82	T
	JB	2	37.72	T
Post	EH	1.33	5	T
	CI	2	20	T
	FJ	1.33	5	T
Strut	DH	1.2	9.09	C
	EI	1.67	12.57	C
	FI	1.67	12.57	C
	GJ	2	9.09	C
Total Length:		24.4		

Truss-2		Length (m)	Force (KN)	C/T
Rafter	AD	1.2	45.45	C
	DE	1.2	36.36	C
	EC	1.2	36.36	C
	CF	1.2	36.36	C
	FG	1.2	36.36	C
	GB	1.2	45.45	C
Tie	AH	2	37.72	T
	HI	2	22.73	T
	IB	2	37.72	T
Post	EH	1.33	10	C
	FI	1.33	10	C
Strut	DH	1.2	9.09	C
	HC	2.24	11.23	T
	IC	2.24	11.23	T
	IG	2	9.09	C
Total Length:		23.54		

Here, I have computed the total length, for Truss-1 it is 24.4 meters, and for Truss-2 it is 23.54 meters. The difference in total length is less than 1 meter which is not an issue at all. Then if we see the highest and the lowest forces in both the cases, then we see that the highest force in Truss-1 is 45.45; and for Truss-2 also it is 4545 there is no difference. In case of lowest force, in Truss-1, it is 5, and in Truss-2 it is 9.09; there no not very huge difference in between them. This much of difference is very much comparable.

So, the design will be almost similar. The amount of steel required for both the cases will be almost equal, the difference can be negligible. So, we can say that we cannot report one truss is more advantageous than the other. There is no any kind of notable benefit we can get from one specific Truss. If we use Truss-1 or Truss-2, both will give us mostly the same typical type of solutions.

Now, let us go to the another set of Truss. Truss-A and Truss-B as shown in Figure-21. If you remember, in the last lecture we have solved this these Truss. In Truss-A, the span is 8 meters with node to node distance of 2 meters, rise of the Truss is 1.5 meters. The bottom chord nodes are marked as L1, L2, L3, L4, and L5; and top chord nodes are marked as U1, U2, U3, U4, and U5; and all the forces on top chord are given to you. Total load on the top chord is 50 KN.

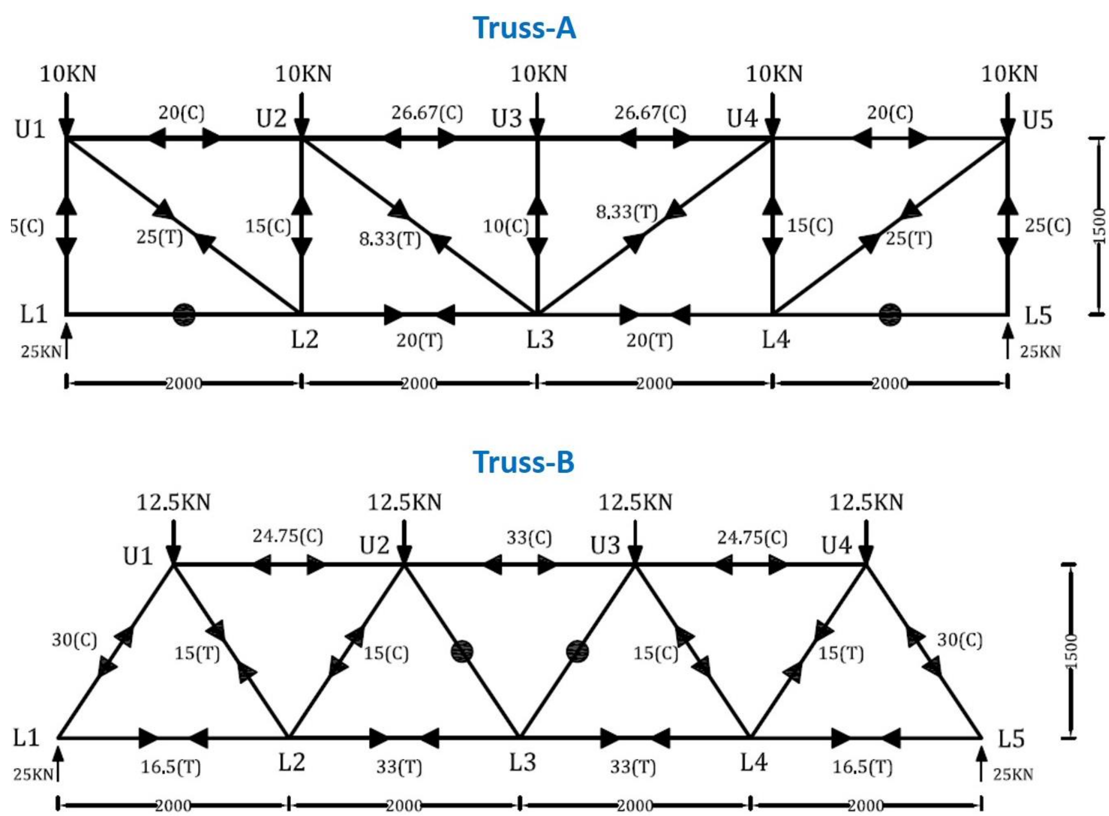

Figure 21 : Truss-A and Truss-B

Truss-B is also having a span of 8 meters, with rise of 1.5 meters. The bottom chord nodes are marked as L1, L2, L3, L4, and L5; and top chord nodes are marked as U1, U2, U3, and U4; and simply supported at L1 and L5. All the forces on top chord are given to you. Total load on the top chord is 50 KN. Refer Figure-21. We have solved this one too.

Now, I have taken these two Truss altogether, and let us see what all will be the differences. We will look it in a tabular format, as shown in Table-2.

Table 2 : comparison of Truss-A and Truss-B

TRUSS-A		Length (m)	Force (KN)	C/T
Top Cord	U1U2	2	20	C
	U2U3	2	26.67	C
	U3U4	2	26.67	C
	U4U5	2	20	C
Bottom Cord	L1L2	2	0	
	L2L3	2	20	T
	L3L4	2	20	T
	L4L5	2	0	
Post	U1L1	1.5	25	C
	U2L2	1.5	15	C
	U3L3	1.5	10	C
	U4L4	1.5	15	C
	U5L5	1.5	25	C
Diagonal	U1L2	2.5	25	T
	U2L3	2.5	8.33	T
	U4L3	2.5	8.33	T
	U5L4	2.5	25	T

TRUSS-B		Length (m)	Force (KN)	C/T
Top Cord	U1U2	2	24.75	C
	U2U3	2	33	C
	U3U4	2	24.75	C
Bottom Cord	L1L2	2	16.5	T
	L2L3	2	33	T
	L3L4	2	33	T
	L4L5	2	16.5	T
Diagonal	U1L1	1.8	30	C
	U1L2	1.8	15	T
	U2L2	1.8	15	C
	U2L3	1.8	0	
	U3L3	1.8	0	
	U3L4	1.8	15	C
	U4L4	1.8	15	T
	U4L5	1.8	30	C

Here, if we go to the Top Chord, we will see that in both the cases it is always under compression and the Bottom Chord is under tension. Hence, it is following the property of the beam the system of the beam, that is good. Next, when we see the Post in Truss-A, we see that they are under compression and the diagonals are under tension, whereas, in case of Truss-B there is no Post, it only has diagonals; and in that there is a mixed variety of compression and tension in alternate manner. Even in Truss-A where the Posts are under compression and diagonals are under tension, it also occurs in alternate manner. It maintains a rhythm in both the Truss. We have noticed it in previous example, in the Pitch Truss too, where the internal forces are either compression or tension and there is a rhythm in it. If you go to go to the Truss-A, you see tension, tension and tension. So, from these, we can say that Truss-A and Truss-B behaves similarly.

Now, if we see the forces, the highest and lowest forces then, we notice that in Truss-A the highest force is 26.67 on Top Chord and lowest force is 0, but other than that it is 8.33. Whereas, in Truss-B the highest force is 30 on diagonal and lowest force is 15. So, if we see the differences then, the difference in highest force is not much, that is comparable. But, the in case of lowest force, the difference is very high; and Truss-B is a bit compacted. So, other than that there is nothing much difference.

Next, let us go to another two set of Truss. Now, I have taken Truss-A1 and Truss-A2 which is a typical variety of Truss A, and shown in Figure-22. Because if you see Truss-A is having an 8 meters span and 1.5 meters of the depth. Here I have kept the load and the span as same, but increased the depth by 500 mm and made it 2 meters. The Truss is simply supported at L1 and L5. So, the only change is the depth of the Truss. Therefore, we can say that definitely there will be some changes in the forces.

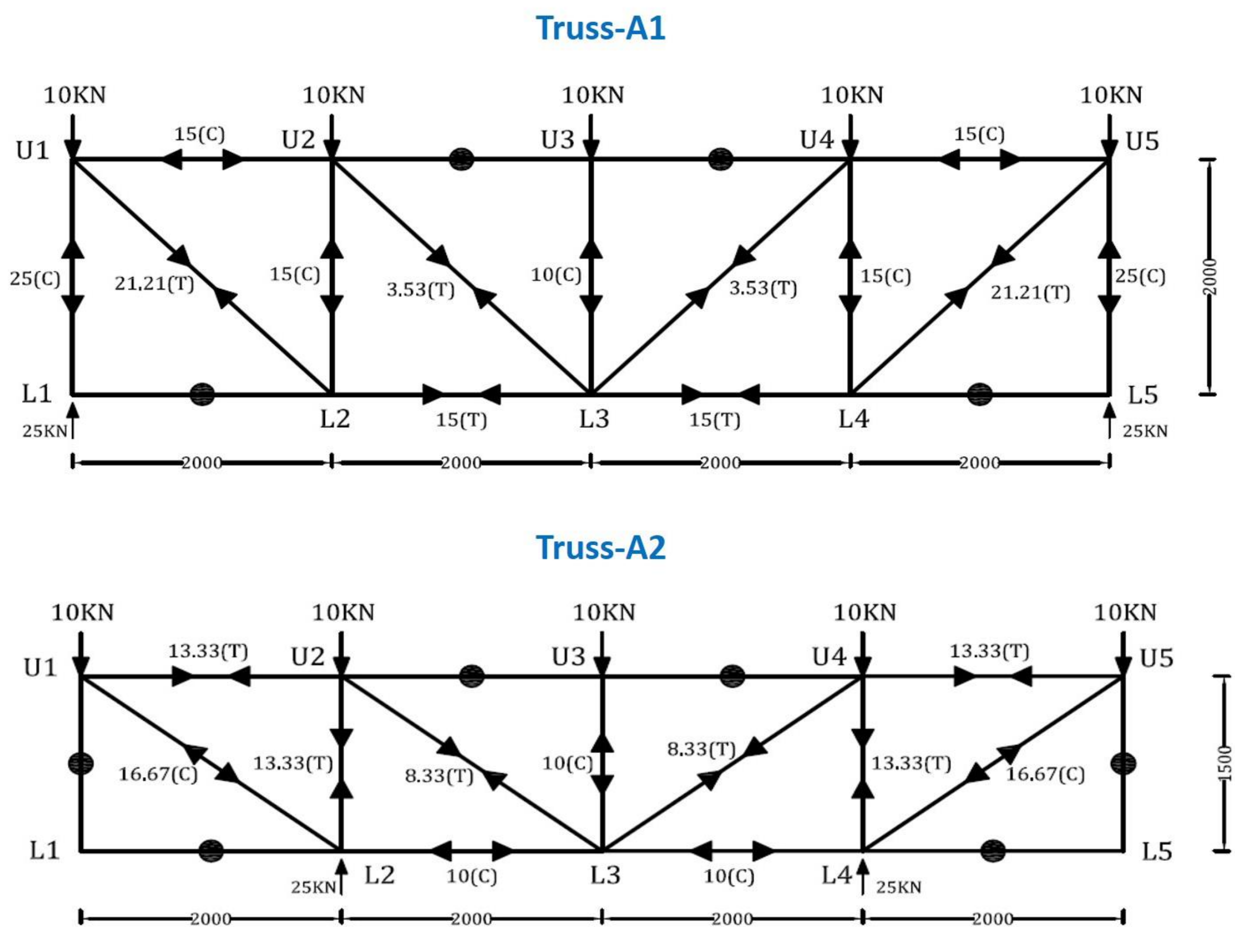

Figure 22 : Truss-A1 and Truss-A2

In Truss-A2 what I did is that I have pushed the support to L2 and L4, it is no more at L1 and L5. Hence the span of the Truss is reduced to 4 meters; and the portion L1 to L2 and L4 to L5 is now cantilevered. So, this Truss is now having two overhanging portions; and it is simply supported at L2 and L4. The depth remains as 1.5 meters. I solved this Truss too.

After solving these two Truss I found one interesting change with respect to Truss-A. In Truss-A, all forces on Top Chord is under compression where as in these cases it is changed.

Anyway, let us fist go to the analysis part this. Here we will compare Truss-A, Truss-A1, and Truss-A2.

Table 3 : Truss-A, Truss-A1, and Truss-A2

TRUSS-A		Length (m)	Force (KN)	C/T	TRUSS-A1		Length (m)	Force (KN)	C/T	TRUSS-A2		Length (m)	Force (KN)	C/T
Top Cord	U1U2	2	20	C	Top Cord	U1U2	2	15	C	Top Cord	U1U2	2	13.33	T
	U2U3	2	26.67	C		U2U3	2	0			U2U3	2	0	
	U3U4	2	26.67	C		U3U4	2	0			U3U4	2	0	
	U4U5	2	20	C		U4U5	2	15	C		U4U5	2	13.33	T
Bottom Cord	L1L2	2	0		Bottom Cord	L1L2	2	0		Bottom Cord	L1L2	2	0	
	L2L3	2	20	T		L2L3	2	15	T		L2L3	2	10	C
	L3L4	2	20	T		L3L4	2	15	T		L3L4	2	10	C
	L4L5	2	0			L4L5	2	0			L4L5	2	0	
Post	U1L1	1.5	25	C	Post	U1L1	2	25	C	Post	U1L1	1.5	0	
	U2L2	1.5	15	C		U2L2	2	15	C		U2L2	1.5	13.33	T
	U3L3	1.5	10	C		U3L3	2	10	C		U3L3	1.5	10	C
	U4L4	1.5	15	C		U4L4	2	15	C		U4L4	1.5	13.33	T
	U5L5	1.5	25	C		U5L5	2	25	C		U5L5	1.5	0	
Diagonal	U1L2	2.5	25	T	Diagonal	U1L2	2.83	21.21	T	Diagonal	U1L2	2.5	16.67	C
	U2L3	2.5	8.33	T		U2L3	2.83	3.53	T		U2L3	2.5	8.33	T
	U4L3	2.5	8.33	T		U4L3	2.83	3.53	T		U4L3	2.5	8.33	T
	U5L4	2.5	25	T		U5L4	2.83	21.21	T		U5L4	2.5	16.67	C

Now, first if we see the Top Chord then in Truss-A, and Truss-A1, the forces are under compression and Truss-A1 has two null forces (which is not an issue). On the other hand, Top Chord of Truss-A2, the forces are under tension with two null forces. That means the cantilever portion will have tensile force. Next, when we see the Bottom Chord, forces in Truss-A, and Truss A-1 will be under tension (with two null forces). Whereas, in Truss-A2 the Bottom Chord will have tensile forces.

Therefore, this has to be understood that in simply supported condition the forces on Top Chord and Bottom Chord are similar, that is top compression and bottom tension. But when support changes and the cantilever come, then it is top tension and bottom compression. This is the first notable difference.

Then we will see the Posts and Diagonals. In Truss-A and Truss-A1, the simply supported condition, the Posts are under compression and Diagonals are under tension. Whereas, in cantilever Truss, Truss-A1, the Posts and Diagonals are under combination of tension and compression, maintaining a rhythm.

So, based on nature of the force, first we have noted the differences.

Next, let us see from magnitude point of view, that is what is the highest or lowest force in these Truss.

In Truss-A, highest force is 26.67, in Truss-A1 it is 25, where the difference is more than 1. It happened to because I have increased the depth of the Truss. So, the highest force is now lowered, because the depth is increased to 2 meters. If I further increase the depth and again compute it, definitely I can get much less than 25. It has to be because now increase in depth will lead you to much more decrease in the load. Then, if we see the lowest force, other than 0, then in Truss-A it is 8.33; and in Truss-A1 it is 3.53. So, in lowest also there is a variation.

Next, if you compare Truss-A with Truss-A2, then highest force in Truss-A is 26.67; and in Truss-A2 it is 16.67 only. See, we are having the same depth, there is only a slight change in the support location, which results into very, very lower force compared to Truss-A. Then the lowest force remains as 8.33 in both the cases.

Hence, from all these comparisons we can say that, the Truss-A2 is very compact. Or I can say that the highest force is reduced by a considerable amount by two way cantilevering of the Truss. This is one of the very important things what we have understood from this particular analysis.

So, I have written over here that Truss with higher depth and 2-way overhang produces the better result.

I have taken the reference of those books for to prepare this particular lecture:

- **Structure as Architecture** by Andrew W. Charleson, Elsevier Publication
- **Basic Structures for Engineers and Architects** by Philip Garrison, Blackwell Publisher
- **Structure and Architecture** by Meta Angus J. Macdonald, Elsevier Publication
- **Examples of Structural Analysis** by William M.C. McKenzie
- **Engineering Mechanics** by Timishenko and Young McGraw-Hill Publication
- **Strength of Materials** By B.C. Punmia, Ashok K.Jain & Arun K.Jain Laxmi Publication
- **Understanding Structures: *An Introduction to Structural Analysis*** by Meta A. Sozen & T. Ichinose, CRC Press

From the conclusion point of view, I must say that the suitable framing system is essential for any Truss design and it is integral part of the Truss system. We have seen the different type of system like purlins and diagonals are required to make an integrated system of Truss. Force distribution in the Truss is based on the geometry and the support position what we have just now understood by virtue of two three typical types of geometrical variety, the depth variety and the support variety etc. From that we can conclude that yes, the force distribution changes, pattern distribution changes.

So that is all for this particular lecture.

In the next lecture we will go to “Application of Truss in Architecture” which will be the fourth lecture in the module 5.

Thank you very much.