Sudan University of Science and Technology

College of Graduate Studies

THE STRUCTURAL PERFORMANCE OF VIERENDEEL FRAMES USING APPROXIMATE METHOD AND COMPUTER PROGRAMS

الأداء الهيكلي لإطارات الفرنديل باستخدام الطريقة التقريبية و برامج الحاسوب

A These Submitted for Partial Fulfilment for the Requirement of M.Sc. Degree in Civil Engineering <u>(Structures Engineering).</u>

Summited By

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بسم الله الرحمن الرحيم

قال تعالى:

{اقْرَأْ باسْمِ رَبّكَ الَّذِي خَلَقَ * خَلَقَ الإِنْسَانَ مِنْ عَلَق * اقْرَأْ وَرَبُّكَ الأَكْرَمُ * الَّذِي عَلَّمَ بِالْقَلَمِ * عَلَّمَ الإِنْسَانَ مَا لَمْ يَعْلَمْ} [العلق: 1-5].

صدق الله العظيم

Abstract

The Vierendeel girder definition is open-frame N-truss without diagonal members, with rigid joints between the top and bottom chords and the verticals are known also as open-frame girder, this research is conducted to study the structural performance of different Vierendeel frame. Three models of the Vierendeel (1, 2& 3) were studied for their structural performance using approximate method and structural analysis programs such as SAP2000 and ROBOT STRUCTURAL for different loadings that were calculated according to British code BS 5950. The results of the analysis were illustrated in graphical presentations. It was taken the differences in bending moments and shear forces for the three models and they were tabulated by approximate method and SAP 2000 and Robot 2015. It was found that the maximum values of bending moments and shear forces were in Vierendeel model (1), and that the minimum values of bending moments and shear forces were in Vierendeel model (3). After examining the structural performance of the three models and comparing the results with each other, it was observed that the Vierendeel model (3) is better compared to the Vierendeel model (1) and (2).

المستخّلص

تعريف العارضة فيرنديل هو الإطار المفتوح N–الجمالون دون أعضاء قطري ، مع المفاصل جامده بين اعلي وأسفل الحبال والقطاعات المعروفة أيضا كعارضه مفتوحة الإطار ، وهذا البحث أجري لدراسة الأداء الهيكلي لمختلف الإطار فيرنديل. وقد درست ثلاثه نماذج من فيرنديل (1 ، 2 و 3) لأداءها الهيكلي باستخدام طريقه تقريبيه وبرامج التحليل الانشائي مثل SAP2000 وROBOT STRUCTURAL لحمولات مختلفه التي تم حسابها وفقا للكود البريطاني BS 5950. وتم توضيح نتائج التحليل في العروض الرسوميه. وقد اتخذت الاختلافات في لحظات الانحناء وقوات القص للنماذج الثلاثة وانها كانت مجدولة بطريقه تقريبيه و SAP 2000 والروبوت 2015. ووجد ان القيم القصوى للحظات الانحناء وقوات القص كانت في نموذج فيرنديل (1) ، وان القيم الدنيا للحظات الانحناء وقوات القص كانت في نموذج فيرننديل (3). وبعد دراسة الأداء الهيكلي للنماذج الثلاثة ومقارنه النتائج مع بعضها البعض ، لوحظ ان نموذج فيرننديل (3) أفضل مقارنه بنموذج فيرنديل (1) و (2).

ACKNOWLEDGEMENTS

First I would like to thank the God, without the God, I could not have the Lowest level of knowledge much less completed this research. I am heartily thankful to my supervisor; **Dr: ABUSAMRA AWAD ATTALEMANAN**, whose encouragement, guidance and support from the initial to the final level enabled me to develop an understanding of the subject.

Also, my heartfelt thanks to my Mom and Dad, my family and my entire friend who have contributed the lions share in the success of my life yet. Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the research.

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CHAPTER ONE

INTRODUCTION

1.1. Introduction

Increase in the actual use in construction of frames with stiff connecting joints, composed of rectangular elements, the proper treatment of indeterminate stresses has been given considerable attention in years. The Vierenedeel frame is one of the important examples of such frames.

With the development and progress in the field of engineering, this study has been a key to open the way for further studies in this area in order to capture the progress in the methods of construction and the promotion of architecture in Sudan to keep up with the development in the world, while the vierendeel models provide a large area can be exploited optimally. And the great development in the use of computer programs in analysis and design, which helps to study the behaviour of complex facilities and simplify their understanding, for example the programs used in this research "Sap2000 and Robot structural ", give more accurate results compared to traditional scientific methods such as the approximate method also used in this research.

1.2. The problem Statement

There is no satisfied study about analysis and uses to vierendeel frame in multi-story building in Sudan. Also the non-existent cognition in vierenedeel uses and favors in order to reduce interior columns and to increase plan area. Without understanding of Vierendeel frame and dealing with it there will not be actual progressing in construction field in Sudan. This research offers an example to analysis some cases of vierendeel and to open the way for future studies in this field.

1.3. Research objectives

The objectives of this research may include the following topics:

1- Study of structural behaviour of three models of vierendeel.
2- Aware of different methods that were used in the Vierendeel analysis, and use approximate method for three model.
3- The use of software package for analysis of vierendeel.
4- Comparison between approximate method and computer programs to get the more effective type of vierendeel models.

1.4. Methodology

The methodology adopted to achieve the above mentioned objectives of this study are:

1- Literature Review is basic concepts will be revised and related literature and relevant data will be collected. Then, the main features of the proposed work will be pointed out.

2- Approximate method will be studied to analysis of vierendeels

3- The analytical software programs (SAP 2000-v18 and Robot Structural analysis) were used to analyze three types of vierendeels.

1.5. Research Organization

In This research was divided into five chapters:

Chapter one contains introduction, the problem, Research objectives, methodology, and organization of the research. Chapter two contains an overview of the literature in vierendeel in general and Statics of the vierendeel Girder. Chapter three presents the introduction in theory of analysis and analysis of vierendeel itself. Chapter four presents analysis of three cases of vierendeel and contains the result and discussion of results. Chapter five presents recommendations and conclusion with suggestion for further projects of the research.

CHAPTER TWO

LITTERATURE REVIEW

2.1. History of Vierendeel

The Vierendeel is a frame with rigid joints patented in 1896 by Belgian engineer Arthur Vierendeel (1852-1940). His invention came about after he noticed that experiments and calculation methods on iron and steel frameworks didn't agree, making his invention a response in the then discussion on secondary stresses. After designing a church tower and testing a full-scale bridge model during the 1897 Brussels World Fair, many bridges, vierendeel system were erected the following decades in his homeland, as well as a few dozens around the globe. At times the discussion on the vierendeel got heated in trade journals and amongst people, mainly due to a lack of visual safety and theoretical uncertainties concerning calculation, safety factors and welding techniques. Nowadays the vierendeel principle is still topical and many structural designers apply his formal ideas. This led to a broader meaning of the word vierendeel varying from aesthetic to strictly structural.

In April 1897, Vierendeel published the structural theory of his "poutre à arcades" as he used to call his invention, initially in his book "Longeronsen Treillis et Longerons". Examples of structures with fully rigid joints were very uncommon at the time. He could only refer to the "Dadizele" church tower. Vierenedeel mentions his system for the first time in public at the Congress International des Architects in August 1897 in Brussels. There he also revealed his upcoming test on a 31.5 m span bridge he was going to build at his own expense within the scope of the Brussels World Fair in "Tervuren". It would be loaded to failure to verify the agreement between calculations and measurement.

While Vierendeel's patents describe vaguely the calculations without explaining the trailing theories, his book goes into detail on how to calculate the particular case of a symmetric bridge with parallel flanges and the general case of an asymmetric bridge with non-parallel flanges. Vierendeel's main criticism on contemporary calculation was a discrepancy between analytical structural theory and actual building practice. Calculation assumed to be pin-jointed connections whereas the execution with rivets tended to be more rigid. After "Schwedler and Winkler", German scientific assistant Heinrich Manderla (1853-1889) had described a calculation method in 1880 to determine the additional secondary stresses. He assumed that angular rotations were not possible in a framework. However Vierendeel still thought this method to be incorrect, primarily because the rigid joint was also far from perfect: the truth balanced between a rigid joint and a pin-joint. Dutch engineer J. Schroeder van der Kolk summarized in the Tijdschrift van het Koninklijk Instituut van Ingenieurs (edition 1889-1890) the results of an experiment that listed the secondary stresses of a truss bridge in relation to the primary stresses. It was striking that those secondary stresses could not be ignored, as they amounted up to 60 % of the primary stresses. Secondly, Vierendeel indicated that in the diagonals the secondary stresses were limited (ranging from 6 to 16 % of the primary stresses). In other experiments he had noted that deformations in the diagonals were nearly negligible.

Vierendeel also referred to Winkler who tried to lower these stresses by using St. Andreas crosses, i.e. doubling the diagonals. It had already been applied in the Netherlands on some railway bridges between Rotterdam and Amsterdam. German civil engineer Otto Mohr's method was used to calculate the basic structure, along with Manderla's equations. However according to Vierenedeel it didn’t reduce the secondary stresses. After tests in France in 1893 ordered by the state, engineers tried to turn truss bridges into girder bridges by using a lattice-work. Though Vierendeel acknowledged some of the advantages.

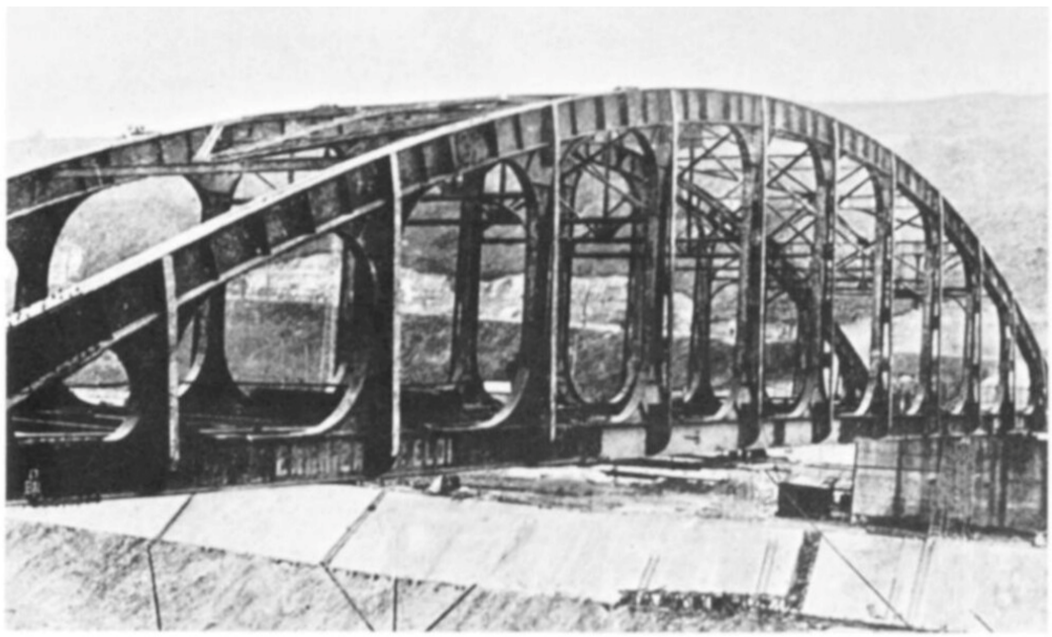


Figure 2.1: The first bridge on the Albert canal.

Reff: Source: Journal of the Society of Architectural Historians, Vol. 35, No. 1 (Mar., 1976), pp. 54-60, the Vierendeel

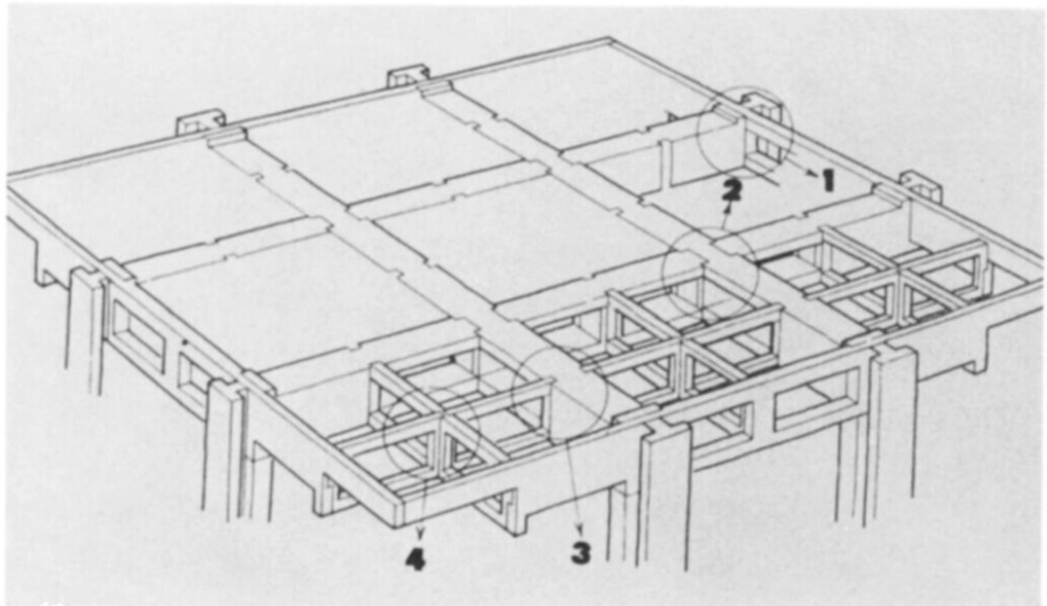


Figure 2.2: Medical research laboratory, university of Pennsylvania.

Reff: Source: Journal of the Society of Architectural Historians, Vol. 35, No. 1 (Mar., 1976), pp. 54-60, the Vierendeel

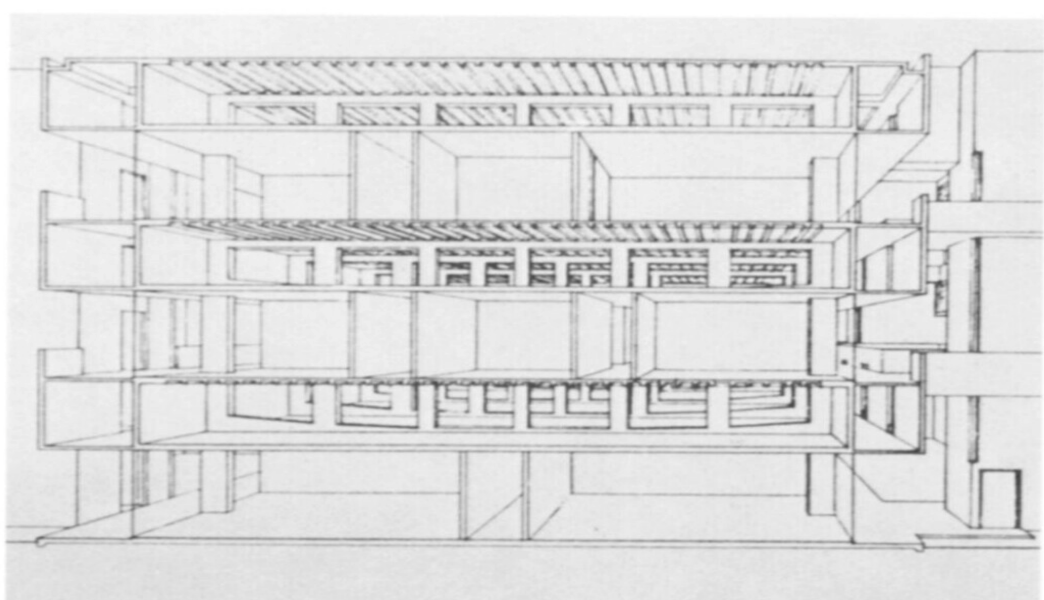


Figure 2.3: San Diego, Salk institute.

Reff: Source: Journal of the Society of Architectural Historians, Vol. 35, No. 1 (Mar., 1976), pp. 54-60, the Vierendeel

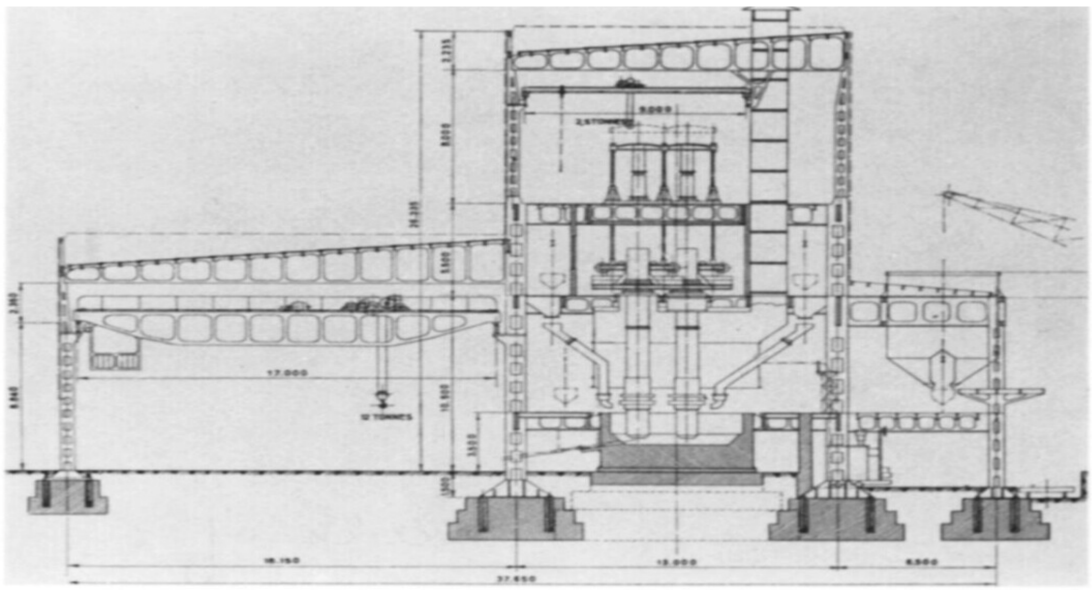


Figure 2.4: Savone, new ILVA steelworks.

Reff: Source: Journal of the Society of Architectural Historians, Vol. 35, No. 1 (Mar., 1976), pp. 54-60, the Vierendeel

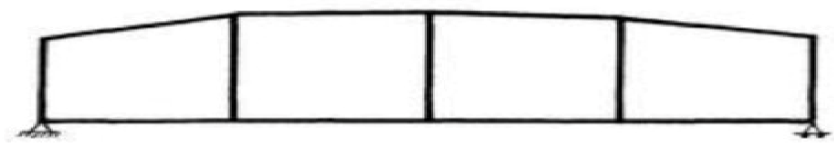
2.2. Definition of Vierendeel

Vierendeels definition as described in his 1899 USA patent is a beam in which the diagonals are removed and the vertical members rigidly connected to the beams by rounded pieces in such manner that the beams and vertical members form practically one piece. Now a day's calculation uses different methods and since the breakthrough of digital calculation more complex algorithms are possible. His name is however still connected to the concept of rigid frames that gain stiffness through these rigid corners. The connotation with the inventor is sometimes lost, but the multifunctional aspects to obtain aesthetic, formal, mechanical or structural plus-points will remain its ace of trumps. However the definition of vierendeel girder is open-frame N-truss without diagonal members, with rigid joints between the top and bottom chords and the verticals are known also as open-frame girder. " David J. Wickersheimer Source: Journal of the Society of Architectural Historians, Vol. 35, No. 1 (Mar., 1976), pp. 54-60, the vierenedeel "

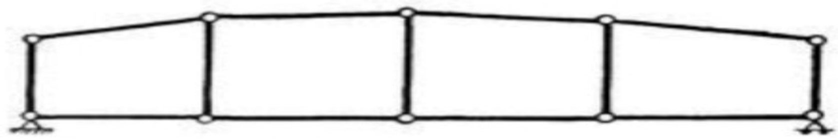
2.3. Statics of the Vierenedeel Girder

2.3.1. Introduction

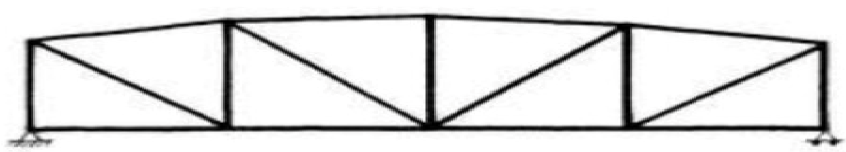
The vierendeel girder, as shown in **Figure 2.5a,** is a framed structure with a high degree of redundancy. In this respect, it is similar to a truss with rigid joints, as shown in **Figure 2.5c.** An exact treatment of the problem necessitates the solution of 3m equations of elasticity, where m is the number of closed panels in the system. Such a procedure involves tedious mathematical calculations and requires a good deal of time. For this reason, the designer is ready to welcome any assumptions, provided that they lead to fairly good results. In the case of a truss, the general practice is to neglect the effect of rigid connections entirely and to assume all members to be hinged at their ends, as shown in **Figure 2.5d.** The structure is thus transformed into a perfect truss, which is stiff enough to carry the external loads. Here, the stiffness of the structure does not require rigid joints. Obviously, the assumption of a hinged truss renders the Solution of the problem very simple. Loads acting at the panel points produce axial forces in the different members. Results thus obtained coincide fairly well with the axial forces produced in a truss with rigid joints, at least for simple triangular systems.



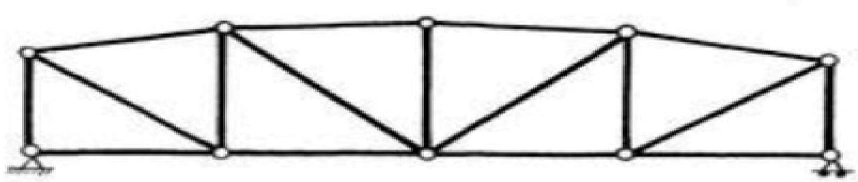
(a) Vierendeel girder.



(b) Deficient hinged system.



(c) Truss with rigid joints.



(d) Truss with hinged joints.

Figure 2.5: Typical configurations of vierendeels.

Reff: El-Demirdash, I.A. Statics of Vierenedeel girder, 21.06.2016

Further, the end moments which exist in the latter cause bending stresses of about 1/3 the normal stresses due to the axial forces. It is understood, that these are accounted for in deciding the working stresses. In short, the hinged truss can be used, in routine calculations, as a fairly good approximation for the actual case of rigid connections. It gives almost correct axial forces and Joint displacements. Consequently, it is suitable also as a main system for an accurate calculation of the rigid truss. Such an approximation, however, is not possible in the case of a vierendeel girder. The absence of the diagonal members renders the system with hinged connections, as shown in **Figure 2.5b**, deficient, and thus incapable of resisting the external loads. Here, rigid joints are necessary for the stiffness of the structure. Further, the end moments produce bending stresses in the different members which cannot be neglected. In this respect, the vierendeel girder differs from the rigid truss.

2.3.2. Exact Methods

The general rule is to refer the redundant vierendeel girder to a statically determinate main system. This is usually done by cutting one of the chord members in every panel, as shown in **Figure 2.6.** The so-formed main system is a simply supported beam. The effect of the redundant values is here limited to one panel only. This is an advantage of the main system. However, the statical behaviour of the Vierendeel girder is far from being similar to that of the simple beam.

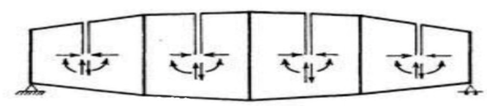


Figure 2.6: The simple beam as main system.

Reff: El-Demirdash, I.A. Statics of Vierenedeel girder, 21.06.2016

On the other hand, if hinges are introduced in the mid-points of the different members, as shown in **Figure 2.6,** a more suitable main system is supplied. This main system behaves more or less similarly to the redundant vierendeel girder. In the latter, the bending moments produced at the ends of the members are much bigger than those which occur at the mid-points. Consequently, the redundant moments at the introduced hinges will be mere corrections. Their

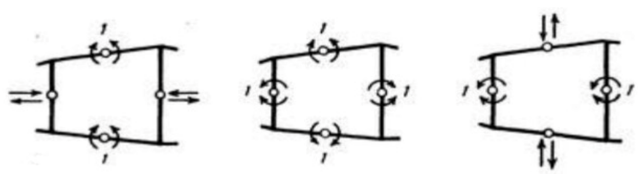


Figure 2.7: Moment groups as virtual cases of loading.

Reff: El-Demirdash, I.A. Statics of Vierenedeel girder, 21.06.2016

Values, and subsequently their effect upon the system, will be less than those in other main Systems. Further, if suitable groups of moments instead of single couples are introduced as Virtual cases of loading, as shown in **Figure 2.7,** the effect of such groups can be restricted to the individual panels where they occur. In this way, the number of unknowns in each equation of elasticity will be reduced, and the exact Solution of the problem is simplified.

In short, the statically determinate main system, which is formed by introducing hinges in the mid-points of the members, is suitable as an approximate method, and also as a main system for an exact calculation of the actual case. As will be seen later, the same hinged system adapts itself very well for the solution of the problem by successive approximations. Further, in the case of a symmetrical vierendeel girder, it is advisable to split up the loads into symmetrical and oppositely symmetrical half loadings. In this way, the number of unknowns and equations will be halved. Finally, in most cases, the coefficients which appear in the elastic equations can be simplified by neglecting the effect of the normal forces on the deformations of the structure. For slender members, this effect is relatively small.

2.3.3. Method of Elastic Couples

This method is applicable to the special case of a vierendeel girder with equal chord stiffness subject to indirect panel-point loading. Neglecting the effect of normal forces, the deflections of the upper and lower chords will be equal. Consequently, the corresponding moments in both chords will be the same, as shown in **Figure 2.8a.** Further, judging by the stresses produced in the flanges of each chord, the corresponding elastic weights will be equal and opposite. These can be combined into elastic couples, which are represented by vectors in the plane of the structure. The verticals give also similar elastic couples. If, now, the vierendeel girder is referred to the main system as shown in **Figure 2.8b,** the moments M° due to the external loads will give the elastic couples C°. Similarly, moments Mr produced by the redundant values will give elastic couples Cr. However, the redundant values being pairs of equal and opposite moments, or forces, produce no reactions. Consequently, corresponding internal forces produced in the upper and lower chords at any vertical section s — s are in equilibrium, as shown in **Figure 2.8c.** In other words, the chord moments in each panel are proportional to the corresponding height. Thus every panel provides one unknown value and the number of closed panels m gives the degree of redundancy of the system.

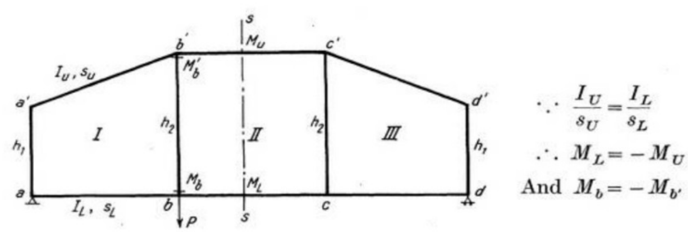


Figure 2.8a: Vierendeel girder of equal chord stiffness.

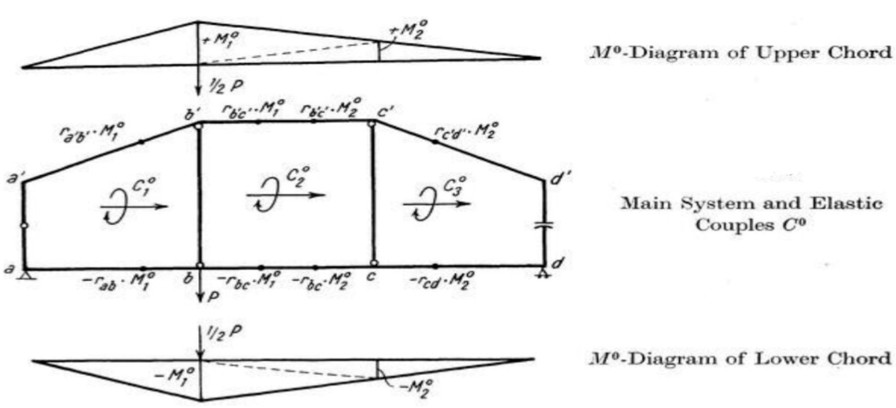


Figure 2.8b: Main system and elastic couples C°.

Reff: El-Demirdash, I.A. Statics of Vierendeel girder, 21.06.2016

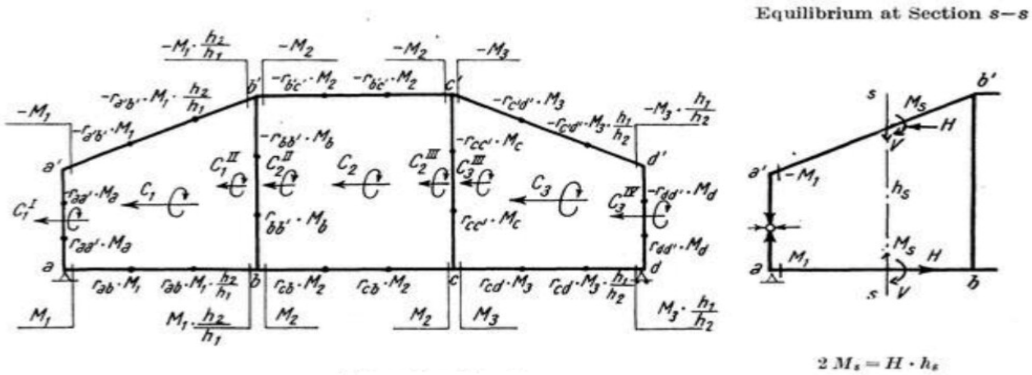


Figure 2.8c elastic couples C_r.

The equilibrium of the elastic couples in every end panel involves two unknown moments, while that of an intermediate panel involves 3 unknown moments. The Solution can be carried out in a progressive manner from panel to panel.

2.3.4. Method of Successive Approximations

In order to avoid the solution of the complicated elastic equations of a highly indeterminate structure, iteration methods are used. The general rule is to simplify the original system by making a suitable assumption of hinges, certain end conditions, approximate joint displacements, etc. The corresponding forces and moments are then determined. They are of course not the same as those of the original structure. Nevertheless, they are used in correcting the first assumption and the whole calculation is repeated for the new conditions. This second step is followed by a third, and so on until the required degree of accuracy is obtained. The success of iteration depends on its convergency. Results of successive approximations should gradually approach the correct values. The number of steps needed for the solution differs according to the nature of the problem and depends on the choice of a suitable assumption. The first obtained values should be real approximations, which are not very far from the accurate results. In this way, successive corrections tend to vanish. Otherwise, the computation will take a long time, involving many steps and corrections, and may not lead to the required results. In the case of a truss with rigid connections, the joint displacements are first assumed to be the same as those of a hinged system. The end moments are then calculated, either directly from the joint rotations by Mohr's method, or successively by relaxation methods. In the latter case, the members are assumed to be fixed at their ends and then relaxed one by one until finally all the system is eased. Either the moments themselves or rotations of the joints are successively corrected. The end moments obtained by the first approximation can be used in correcting the displacements of the joints which have been assumed at first. The calculations are then repeated for the new values and a second approximation of the end moments obtained. The whole process may be continued until no further corrections are needed. This condition, however, is not always fulfilled, especially for a complicated system of triangulations.

Unfortunately, the Vierendeel girder cannot be treated in the same way. It is impossible to assume all members to be hinged at their ends. However, a girder with equal chord stiffness can be solved successfully by the Panel Method.

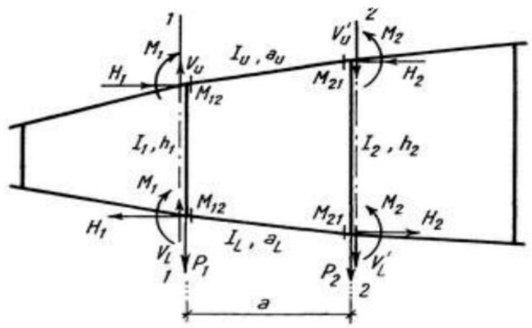
2.3.5. The Panel Method

The idea involved in this method is to split up the vierendeel girder into single closed panels, as shown in **Figure 2.9a,** and to consider the equilibrium of each panel separately. Assuming every panel to be hinged at both sides to the rest of the structure, the effect of external loads gives the so-called primary moments as shown in **Figure 2.9b.** The connecting moments at the introduced hinges just outside the four corners produce secondary moments in the closed panel as shown in **Figure 2.9c.** The sums of the primary and secondary moments give the required moments of the vierendeel girder. In the special case of a vierendeel girder with equal chord stiffness, the corresponding moments in the upper and lower chords will be equal. It is, therefore, possible to derive a simple expression for the primary and secondary moments which can be applied to every closed panel in the system. Referring to **Figure 2.9b and 2.9c:**

$$M'_{12} = \frac{\alpha M - V a}{2D}[3 + s + \alpha(2 + s)] \qquad M''_{12} = \frac{r}{D} \cdot M_1 - \frac{s(1+\alpha)}{D} \cdot M_2$$

$$M'_{21} = \frac{\alpha M - V a}{2D} \cdot (3 + r + \alpha) \qquad M''_{21} = -\frac{r(1+\alpha)}{D} \cdot M_1 + \frac{s(1+\alpha)^2}{D} \cdot M_2$$

Hence $M_{12} = M'_{12} + M''_{12}$ and $M_{21} = M'_{21} + M''_{21}$



$$k_1 = \frac{I_1}{h_1}, \qquad k_2 = \frac{I_2}{h_2}, \qquad k = \frac{I_U}{a_U} = \frac{I_L}{a_L}$$

$$r = \frac{k}{k_1}, \qquad s = \frac{k}{k_2}, \qquad \alpha = \frac{h_2 - h_1}{h_1}$$

$$D = 6 + r + s + \alpha\,(2\alpha + \alpha s + 2s + 6)$$

$$V_1 = V_U + V_L, \qquad V = V_1 - P_1, \qquad H_1 = \frac{M - 2M_1}{h_1}$$

Figure 2.9a: Single closed panel of vierendeel girder.

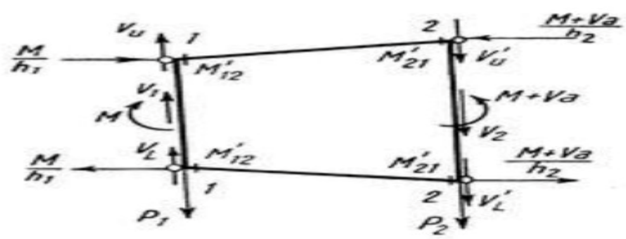


Figure 2.9b: Primary moments.

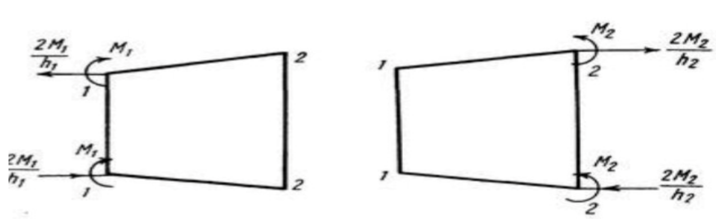


Figure 2.9c: Secondary moments.

Reff: El-Demirdash, I.A. Statics of Vierendeel girder, 21.06.2016

At first, the primary moments are determined for the whole girder. They are considered to be first approximations of the actual end moments. Consequently, the secondary moments in each panel can be calculated. The sums of corresponding values give a second approximation of the end moments, which can be used in correcting the secondary moments obtained before. In this way a third approximation of the end moments is obtained, and so on. The process is continued until it converges.

2.3.6. Modification of the Panel Method

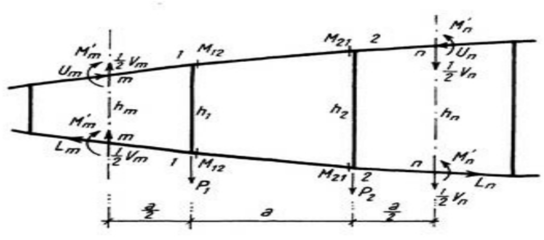
The panel method just explained assumes every closed panel to be hinged at its four corners to the rest of the structure. Unfortunately, the bending moments of the vierendeel girder are maximum at these points and big values of connecting moments are expected. Moreover, the so-called secondary moments will not be small compared with the primary moments, being sometimes almost of the same order. This explains why several steps are needed to bring the successive approximations to an end. In order to simplify calculations and to reduce the number of corrections, it is necessary to adapt the assumption to the real behaviour of the structure. This can be done by introducing the hinges at the mid-points of the different members where the bending moments are small. In this way, every element is considered to be built up of a closed panel with overhanging arms, which extend to the middle of the adjacent panels **Figure 2.10**. The secondary moments produced by the connecting moments are very small compared with the primary moments due to the external loading. They are real corrections of small magnitude. The process converges after very few successive approximations. In determining the values of the primary moments, the forces acting at the ends of the overhanging arms are shifted parallel to themselves to sections 1 — 1 and 2 — 2 respectively. Four couples are introduced at the 4 corners of the closed frame. Owing to the fact that the vierendeel girder has in this case equal chord stiffness, the additional couples at the corresponding joints of the upper and lower chords will be the same. They are represented by Mx' and M_2 respectively. Thus:

$$M = M_m + V_1 \cdot \frac{a}{2} = \frac{M_m}{h_m} \cdot h_1 + 2\,M_1'$$

and $$M' = M_n - V_2 \cdot \frac{a}{2} = \frac{M_n}{h_n} \cdot h_2 + 2\,M_2'$$

or $$M_1' = \frac{M_m\,(h_m - h_1)}{2\,h_m} + V_1 \cdot \frac{a}{4} = \frac{h_1}{2}\left(\frac{M}{h_1} - \frac{M_m}{h_m}\right)$$

and $$M_2' = \frac{M_n\,(h_n - h_2)}{2\,h_n} - V_2 \cdot \frac{a}{4} = \frac{h_2}{2}\left(\frac{M'}{h_2} - \frac{M_n}{h_n}\right)$$



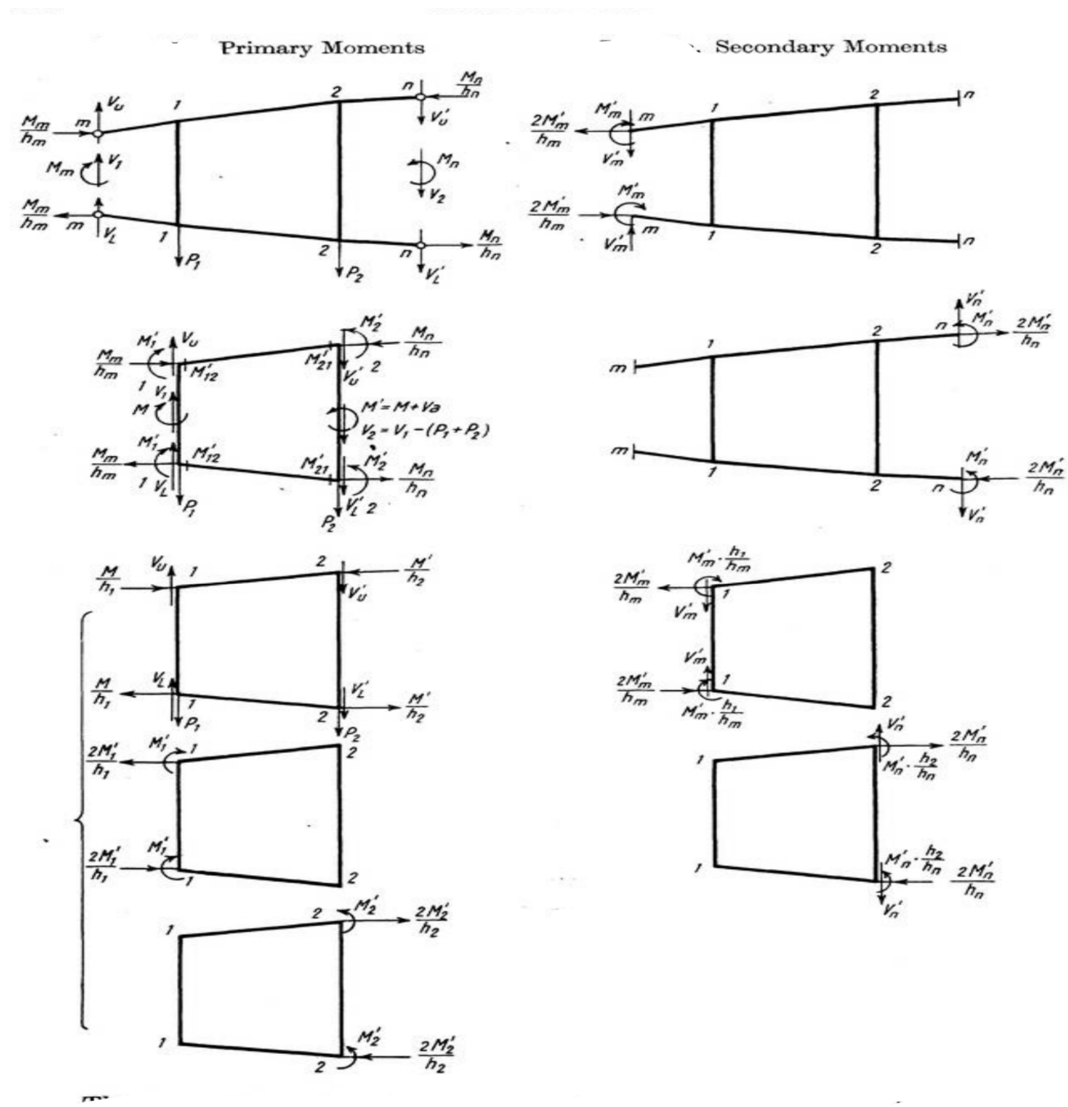


Figure 2.10: Primary moments and secondary moments.

Reff: El-Demirdash, I.A. Statics of Vierendeel girder, 21.06.2016

The loading thus obtained is further split up into cases of partial loading similar to those of **Figure 2.10**. In this way, it is possible to use the relations found before in determining the new primary moments M_{12} and M_{21}. Thus:

$$M'_{12} = \frac{\alpha M - V a}{2D}[3+s+\alpha(2+s)] + \frac{r}{D}\cdot M_1' - \frac{s(1+\alpha)}{D}\cdot M_2',$$

and $$M'_{21} = \frac{\alpha M - V a}{2D}[3+r+\alpha] - \frac{r(1+\alpha)}{D}\cdot M_1' + \frac{s(1+\alpha)^2}{D}\cdot M_2',$$

or $$M'_{12} = \frac{\alpha(M_m + \frac{1}{2}\cdot V_1\cdot a) - V\cdot a}{2D}[3+s+\alpha(2+s] + \frac{r}{D}\cdot\left[\frac{M_m}{2h_m}(h_m - h_1) + V_1\cdot\frac{a}{4}\right] - \frac{s(1+\alpha)}{D}\cdot\left[\frac{M_n(h_n - h_2)}{2h_n} - V_2\cdot\frac{a}{4}\right]$$

and $$M'_{21} = \frac{\alpha(M_m + \frac{1}{2}V_1\cdot a) - V\cdot a}{2D}[3+r+\alpha] - \frac{r(1+\alpha)}{D}\cdot\left[\frac{M_m}{2h_m}(h_m - h_1) + V_1\cdot\frac{a}{4}\right] + \frac{s(1+\alpha)^2}{D}\cdot\left[\frac{M_n}{2h_n}(h_n - h_2) - V_2\cdot\frac{a}{4}\right]$$

The other cases of secondary moments are treated in a similar manner. They supply the new secondary moments M''_{12} and M''_{21}, thus:

$$M''_{12} = \frac{r}{D}\cdot\frac{h_1}{h_m}\cdot M'_m - \frac{s(1+\alpha)}{D}\cdot\frac{h_2}{h_n}\cdot M'_n$$

$$M''_{21} = -\frac{r(1+\alpha)}{D}\cdot\frac{h_1}{h_m}\cdot M'_m + \frac{s(1+\alpha)^2}{D}\cdot\frac{h_2}{h_n}\cdot M'_n$$

The other cases of secondary moments are treated in a similar manner. They supply the new secondary moments M''_{12} and M''_{21}, thus. The steps followed in the successive solution are the same as for the panel method. The primary moments, which serve as first approximation of the actual moments, are first determined. The secondary moments are then calculated and a second approximation of the actual moments is obtained. There is generally no need for a further correction.

Needless to say that the panel method explained before as well as its modification are suitable only for indirect loading and equal chord stiffness of the vierendeel girder.

2.3.7. Conclusion of Statics vierendeel

1. The statics of the vierendeel girder should no more be considered as an obstacle in the way of adopting this type in competitive structural work. The exact calculations can be often replaced by successive approximations. Even if such a procedure seems to be complicated, the designer can resort to fairly good approximate methods by making appropriate assumptions, or by experimental and semi-experimental methods. Especially in the case of steel, the construction of the joints in the vierendeel girder is simplified by welding. There is also no need of having plate girder sections, the members of the vierendeel girder may be of the open web or truss form. Finally, the statics of the vierenedeel girder may be applied in the design of battened compression members, framed buildings and in similar structures.

   " El-Demirdash, I.A. Statics of Vierenedeel girder, 21.06.2016, Persistenter Link: http://dx.doi.org/10.5169/seals-12318"

2.4. Concrete Dimensions

2.4.1. Carry one floor

About this case the vierendeel carry just one floor in above it, and slabs work for one way, it is have thickness of vierendeel (t) and height (h)&(a) of vierendeel depend to length of vierendeel and thickness of column too. All this explain as shown the **Figure 2.11.**

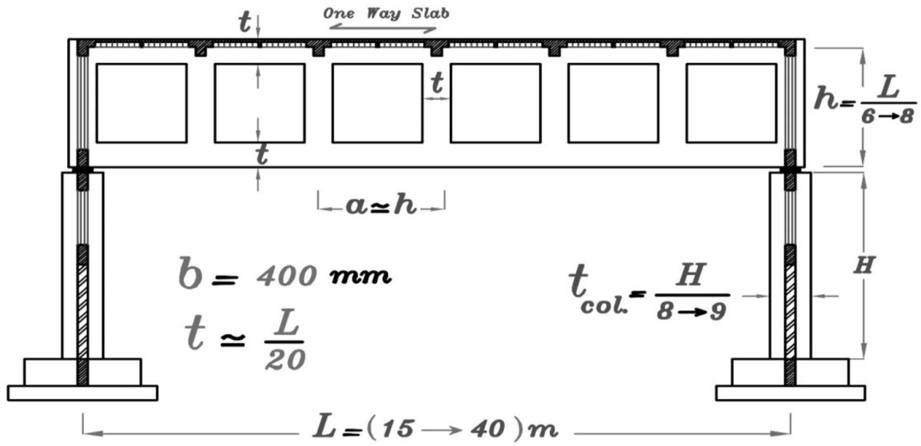


Figure 2.11: Concrete Dimensions for one floor.

Reff: Yasser El-leathy 2016, Vierendeel.

2.4.2. Carry more floors

About this case the vierendeel carry more than three floor in above it, and slabs work for one way, it is have thickness of vierendeel (t)and height (h)&(a) of vierendeel depend to length of vierendeel and thickness of column too. All this explain as shown the **Figure 2.12**.

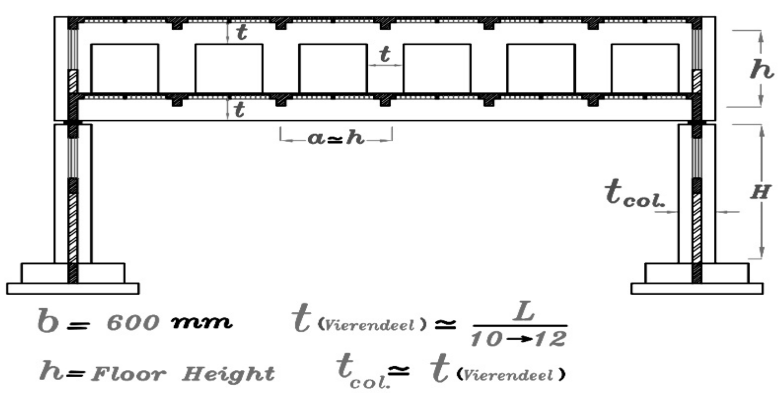


Figure 2.12: Concrete Dimensions for more floors.

Reff: Yasser El-leathy 2016, Vierendeel.

2.5. Vierendeels applications

a) The advantage of being able to carry a several story based on it without the need for columns in the middle.

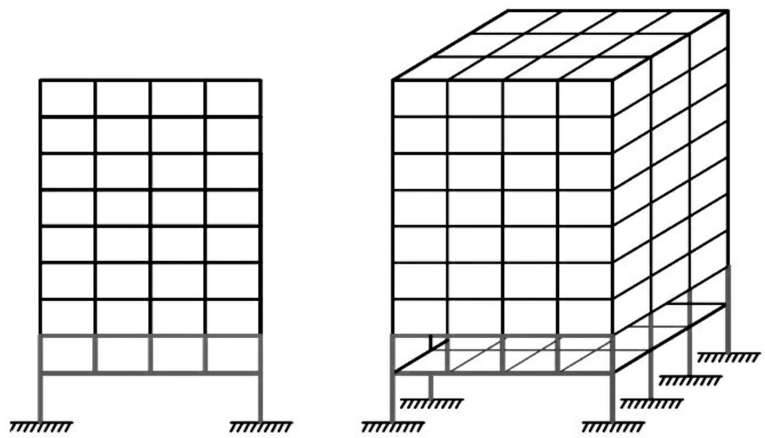


Figure 2.13: Vierenedeels carry a several stories.

Reff: Yasser El-leathy 2016, Vierendeel.

b) Add more floors above old building carry on external columns connected in edge.

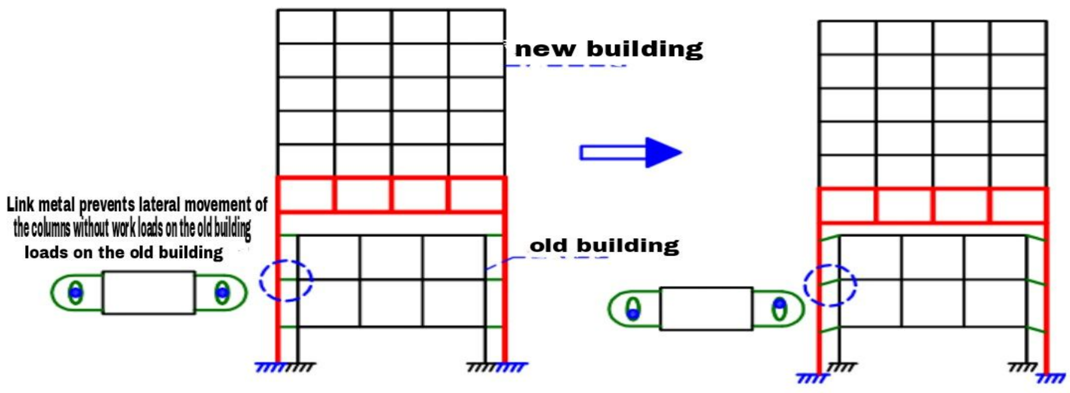


Figure 2.14: Method to add more floors.

Reff: Yasser El-leathy 2016, Vierendeel.

c) Use this in any floors and carry above some floors connected to external columns. (example conference rooms in 5 story)

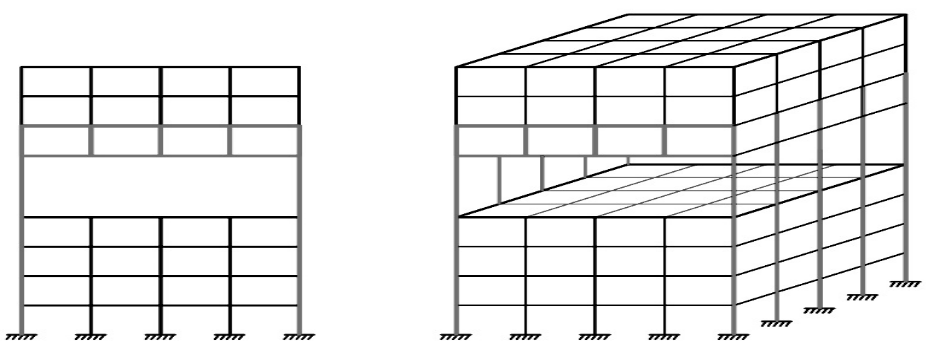


Figure 2.15: Method to use vierendeel for any floors.

Reff: Yasser El-leathy 2016, Vierendeel.

d) Used in cover to big space (more than 20 meters)

" Yasser El-leathy 2016, Vierenedeel."

CHAPTER THREE

METHODOLOGY AND THE CASE STUDY

3.1. Introduction

The main purpose of any structure is to carry loads over or round specified spaces and delivers them to the ground. All relevant loads and realistic load combinations have to be considered in design.

The Vierenedeel is a member of a construction carries live and dead and wind loads of the upper floors are transferred to external columns.

3.2. General Loads

British Standard 5950 classifies working loads into the following traditional types:

(i) Dead loads due to the weight of the structure materials. Accurate assessment is essential.

(ii) Imposed loads due to people, furniture, materials stored, snow, erection and maintenance loads. Refer to BS 6399.

(iii) Wind loads depend on the location, the building size and height, openings in walls etc. Wind causes external and internal pressures and suctions on building surfaces and the phenomenon of periodic vortex shedding can cause vibration of structures. Wind loads are estimated from maximum wind speeds that can be expected in a 50-year period. They are to be estimated in accordance with CP3: Chapter V, Part 2. A new wind load code BS 6399: Part 2 is under preparation.

(iv) Dynamic loads are generally caused by cranes. The separate loads are vertical impact and horizontal transverse and longitudinal surge. Wheel loads are rolling loads and must be placed in position to give the maximum moments and shears. Dynamic loads for light and moderate cranes are given in BS 6399: Part 1.

3.3. Structural loads

The structural loading arises from the dead loads due to the weight of the structure materials. Accurate assessment is essential. Imposed loads due to people, furniture, materials stored. In this research approximate method was used to calculate of load on vierenedeel.

3.4. Calculation of load on vierenedeel by approximate method

In order to calculate loads on vierenedeel by approximate method

- Assume that the equivalent working (Wav)load is:
  Wav (u.l) = (12.0 – 15.0) kN/ m^2 ……………….. (3.1)
- Total Load for One Floor = Wav * Floor area ………. (3.2)
- Total load for the Building is equal to Load of one floor * Number of floor. (Add Weight of ground floor) ………………. (3.3)
- Total load on one vierenedeel is:
  Distribution the total load on number of vierenedeel and assume the first and the last system carry just the half total load.
- Load on one joint of the vierenedeel is:

Distribution the total load of vierenedeel on the number of joints and assume the first and the last joint carry just the half total load.

3.5. Methods for analysis of vierenedeel

3.5.1. Approximate method

If depth of the main supporting girder is relatively big, a vierendeel girder as shown **Figure (3.1)** may in some cases be used.

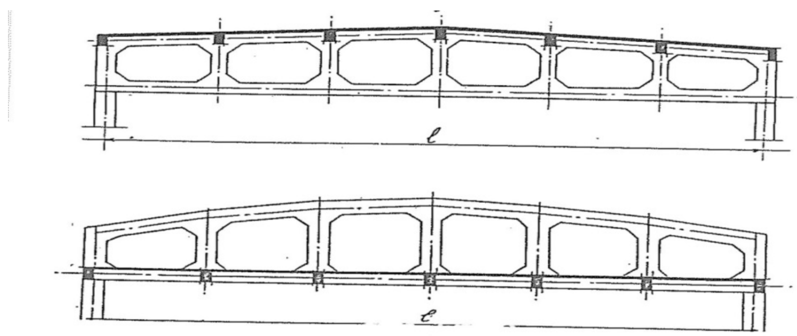


Figure 3.1: Typical Vierendeel girder.

Reff: M. HILAL Design of Reinforcement Concrete Halls 2005

A Vierendeel girder is a high grade statically indeterminate structure composed of a top chord, a bottom chord and verticals only internally, it is (3*n) statically indeterminate; n being the number of the panels as shown **Figure 3.2;** whereas, externally, it may be statically determinate as in simply supported girders or indeterminate as in continuous girders.

The exact solution of a vierenedeel girder is relatively complicate but essential of the members are thin compared to the height of the girder. In reinforced concrete, the dimensions of the different members, chords and verticals are generally big and the following proposed approximate solution is simple and gives acceptable results for normal vierenedeel girders with parallel chords and verticals having equal stiffness. The method can however be applied if the top chord is polygonal, slightly curved or inclined as shown **Figure 3.2.**

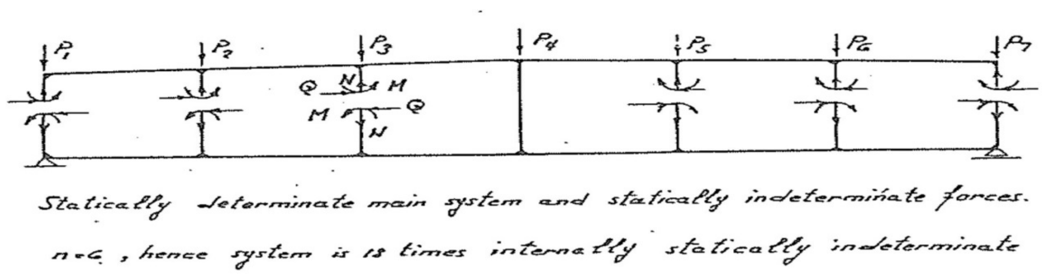


Figure 3.2: Statically main systems.

Reff: M. HILAL Design of Reinforcement Concrete Halls 2005

Considering a vierenedeel girder subject to concentrated loads P_t and P_b acting at the joint of the top and bottom chords as shown **Figure 3.3a.** These loads cause external bending moment's m_I, m_{II} ... etc in the panel a_1, a_2…etc as shown **Figure 3.3c.**

The bending moments in the different members-being not directly loaded – are liner as shown **Figure 3.3a** and can be determined from the external bending moments if the points of zero bending moments in the member are known.

In case of symmetrical vierenedeel girders with equally stiff chords and vertical subject to symmetrical loads, the point of zero bending moments in any of the panels of the top and bottom chords and in the verticals may be assumed at the middle. If we imagine that binges are introduced at the above mentioned points of zero bending moments, the girder will be internally statically determinate and the assuming:

$I_t = I_b$ and $I_1 = I_2$ ......etc are the moments of inertia of the top chord, the bottom chord and the vertical 1, 2,….etc.

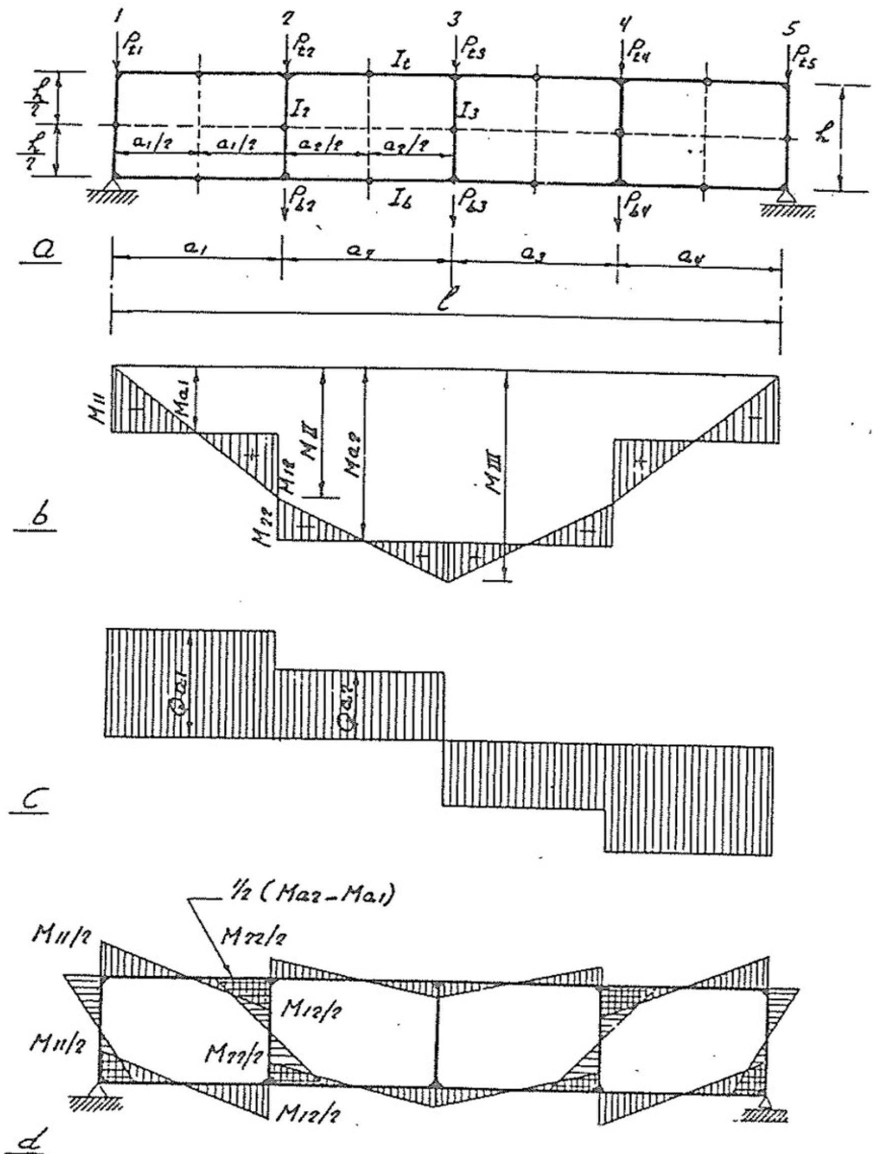


Figure 3.3: Approximated method of analysis.

Reff: M. HILAL Design of Reinforcement Concrete Halls 2005

P_{t1}, P_b, P_1, P_2……………etc. are the normal forces in chord and verticals.

Q_t, Q_b, Q_1, Q_2…………..etc are the shearing forces in chord and verticals.

M_t, M_b, M_1, M_2………..etc are the bending moments in chord and verticals.

As shown **Figure 3.4,** the normal forces in any of the panels say a_1 are given by:

$N_{b1} = - N_{t1} = M_{a1}/ h$ ………………. (3.4)

Tension in the bottom chord and compression in the top. The shearing force Q_{a1} will be equally resisted by the two chords,

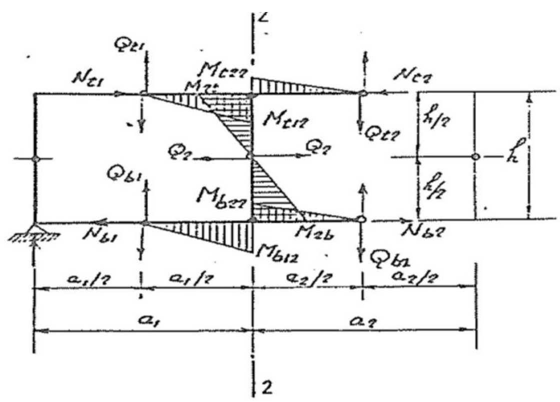


Figure 3.4: The normal forces.

Reff: M. HILAL Design of Reinforcement Concrete Halls 2005

Therefore:

$Q_{b1}=Q_{t1}=Q_{a1}/2$ ………………. (3.5)

It has to be noted here that $Q_{b1}=Q_{t1}$ shown in figure express the vertical component of resultant of the loads and reactions to the left of the vertical through the middle of a_1 and hence their sense is upwards, where

$Q_{b2} = Q_{t2}$ give the vertical component of the resultant of the loads and reactions to the right of the vertical through the middle of a_2 and hence their sense is downwards. The bending moments to the left of vertical 2 are given by:

$M_{b12} = Q_{b1}. a1/2$ ….. (3.6) and $M_{t12} = Q_{t1} .a_1 / 2$ …… (3.7)

Therefore:

$M_{b12} = M_{t12} = Q_{a1}. a_1 / 4$ ………………. (3.8)

Similarly:

$M_{b12} = Mt_{22} = Q_{a2}. a_2 / 4$ ………………. (3.9)

It is recommended to draw the bending moment diagrams on the tension side as shown. The normal force in vertical 2 can be calculated according to **Figure 3.5** from the relation

$N_2 = Q_{t1} - Q_{t2} – P_{t2}$ ………………. (3.10)

$= ½ (Q_{a1} – Q_{a2}) – P_{t2}$ ………… (3.11)

$= ½ (P_{b2} + P_{t2}) – P_{t2}$ ………… (3.12)

$= ½ (P_{b2} – P_{t2})$ ………..……. (3.13)

The bending moments in the verticals can be determined from the equilibrium of the joints as shown in **Figure 3.6;** thus

$M_{2t} = M_{t12} + M_{t22}$ ………………. (3.14)

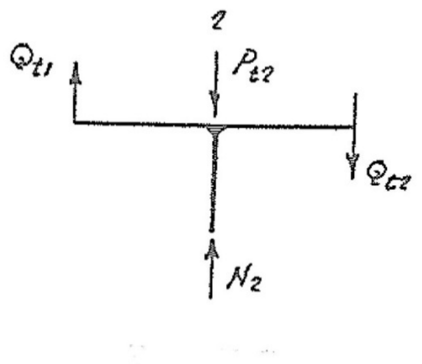
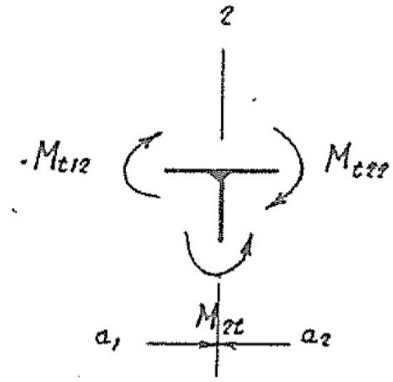



Figure 3.5 and Figure 3.6 The bending moments in the verticals and the equilibrium of the joint.

Reff: M. HILAL Design of Reinforcement Concrete Halls 2005

It has to be noted here that the know moments M_{t22} and M_{t12} are expressed in **Figure 3.6** by arrows giving their sense; i.e. M_{t12} is clockwise (positive) causing tension at the lower fibre and compression at the upper fibre to the left of joint 2, it will therefore be expressed by clockwise arrow from the tension side to the compression side. Whereas M_{t22} is also clockwise but causing tension at the upper fiber and compression at the lower fiber to the right of the same joint. The unknown moments M_{2t} at the upper joint of vertical 2 must keep the equilibrium of the two moments M_{t12} and M_{t22}, therefor its magnitude must be equal to their sum and its sense must be anti-clockwise i.e. causing tension on the left side and the compression on the right side of vertical 2.

The final bending moment diagrams drawn on the tension side are the shown in **Figure (3.4).** The shearing forces at the points of zero bending moments in the verticals can be determined by dividing the bending moments at any of the corresponding joint by h/2.

The shearing force Q_2 and the bending moments M_{2t} and M_{2b} acting on vertical 2 can also be determined as follow:

Referring to **Figure 3.4**, it was found that:

$Q_2 = N_{t1} - N_{t2} = N_{b1} - N_{b2} = -(M_{a2} - M_{a1}) / h$ ………………. (3.15)

$M_{2t} = -M_{2b} = -Q_2.h/2 = -½(M_{a2} - M_{a1})$ ………………. (3.16)

The bending moments in the chords can be determined graphically by drawn vertical lines through the points of zero bending moments of the chords to meet the sides of the external bending moment diagram. Through the points of intersection draw horizontal lines as shown **Figure 3.3;** the diagrams enclosed between these horizontals and the sides of the external bending moment diagram hatched diagrams give the bending moments to be resisted by the two chords. If the chords are equal stiffness, then each chord will resist half the bending moment.

Having determined the bending moments in the chords, the bending moments in the verticals can be determined from the equilibrium of the joint shown the **Figure 3.6.**

The final bending moment diagram drawn on the tension side for the whole vierendeel girder is shown in **Figure 3.3d**; such an illustration is very convenient as it gives the tension side and respectively the position of the longitudinal reinforcement in very part of the girder. It has been further found that the diagonal tension in a beam is in the direction of the sides of the bending moments diagram if it is drawn on the tension side. Hence, the direction of the diagonal tension corresponding to the bending moment shown in **Figure 3.3d** will be the chords and verticals to the left in the left half and to the right in the right half.

If the moments of inertia of the chords or the verticals are not equal, the point of zero bending moments cannot be assumed at the middle of the chords or the verticals and can approximately be determined as follow:

Assume I_t, I_b, I_{v1}, I_{v2}….are the moments of inertia of the top chord, the bottom chord and the verticals 1, 2….etc, and

X_{gt}= a/I_t * I_t/a =1 is the relative rigidity of the top chord ………………. (3.17)

X_{gb} =a/I_b * I_t/a =I_t/I_b is the relative rigidity of the bottom chord. …… (3.18)

$X_v = h/I_v * I_t / a$ is the relative rigidity of the verticals ………. (3.19)

If considering the panel 2-3, length a_2, and assume that the point of zero bending moment in vertical 2 lies at a distance y_2 from the top chord, and that the point of zero bending moment in the chords 2-3 lies at a distance x_2 from vertical 2, **Figure 3.7,** it is possible to prove that:

- $M_{2t}/M_{2b} = y_2/h\text{-}y_2 = (3 X_v + X_{gb}) / (3 X_v + X_{gt}) = C_t$………. (3.20)

And

- $M_{t22}/M_{t23} = x_2/a_2\text{-}x_2 = (3 X_g + X_{v3}) / (3 X_g + X_{v2}) = C_2$ ……. (3.21)

So that

$y_2 = (C_t / (C_t + 1)) * h = k_t * h$ ………………. (3.22)

And

$x_2 = (C_2 / (C_2 + 1)) * a_2 = k_2 * a_2$ ………………. (3.23)

The external shearing force acting in panel a_2 is given by Qa2 and is distributed between the top and bottom chords according to ratios:

$Q_{t2} = k_t * Q_{a2}$ ………………. (3.24)

And

$Q_{b2} = (1- k_t)* Q_{a2}$ ………………. (3.25)

Having known Q_t and Q_b in the different panels the other internal forces can be easily determined as shown before.

If the loads act directly on the top or bottom chords, the bending moments due to these direct loads are to be determined for each chord as a continuous beam supported on the verticals. Such bending moments are to be added to those due to the concentrated loads acting at the joints as shown **Figure 3.8.**

In this case, P_t and P_b are the sum of the direct load on the joint plus the reactions of the top and bottom chords as a continuous beam.

The corners of a vierenedeel girder are subject to high secondary stresses so that girders free from corner cracks can only be obtained by careful study of the reinforcement and very good execution. The use of haunches in the corners is in this respect, where possible, recommended.

The bending moments of this system change their sign in every panel so that a simple arrangement of the reinforcements can only be obtained by careful study. Its deflection is generally bigger than that of solid girders.

It is generally recommended to use this system when it gives the only convenient solution; especially because it is relatively expensive.

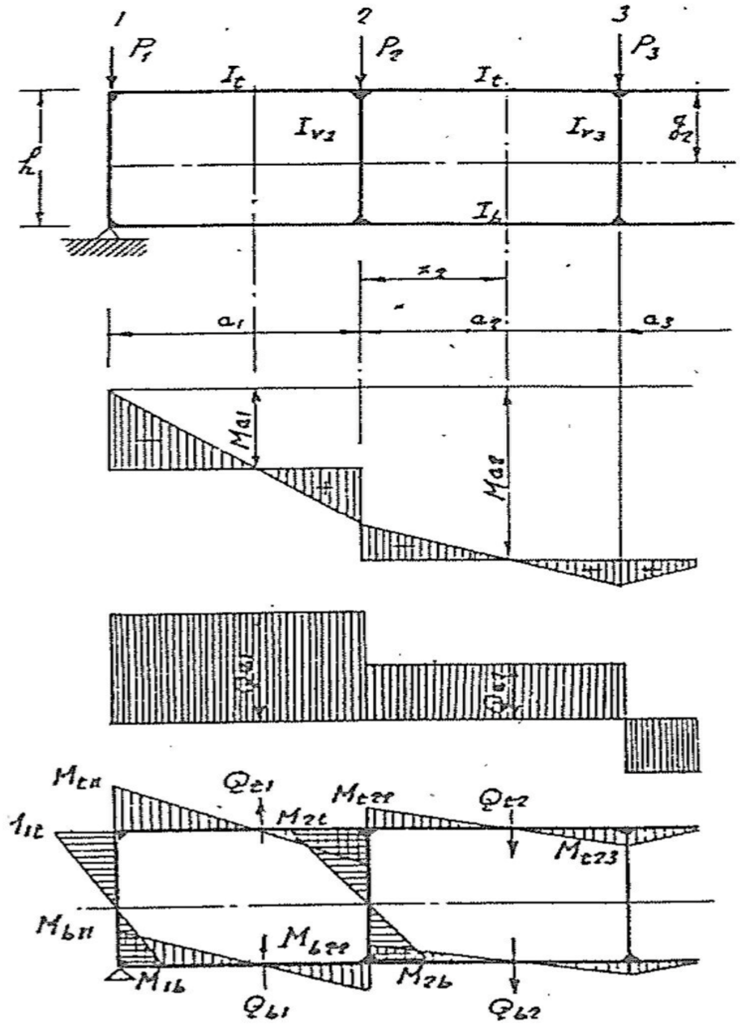


Figure 3.7: Final diagrams.

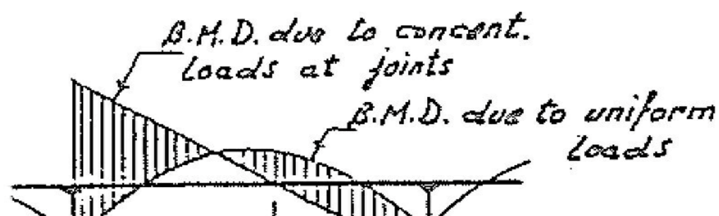


Figure 3.8: Moments in the joints.

Reff: M. HILAL Design of Reinforcement Concrete Halls 2005

3.6. Types of vierenedeel and Diagram by approximate method

3.7.1. Type one

In this case, the vierenedeel as shown in **Figure 3.9** with fixed in two edges. And carry one way slabs as shown **Figure 3.10. Figure 3.11** explains how to draw shear force and bending moment diagrams.

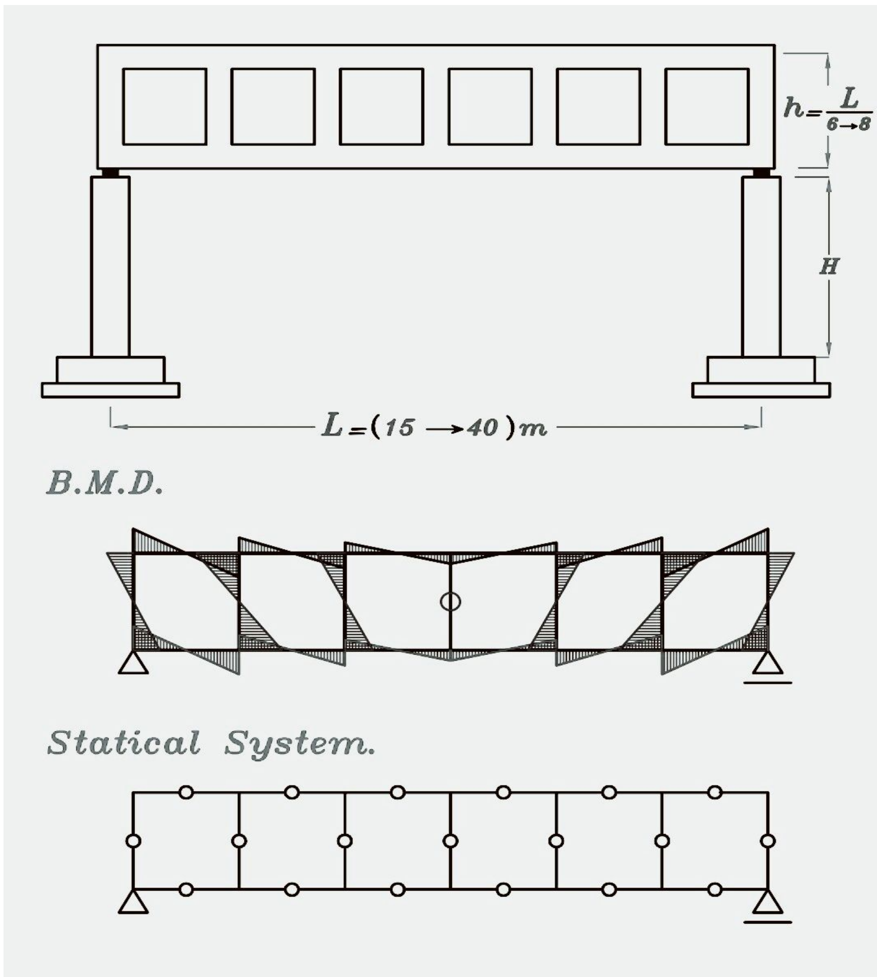


Figure 3.9: Vierendeel without cantilever.

Reff: Yasser El-leathy 2016, Vierendeel.

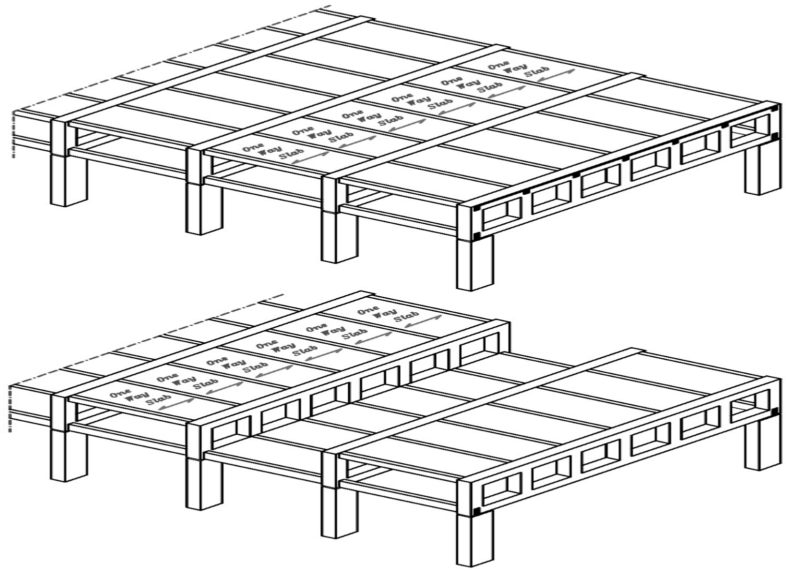
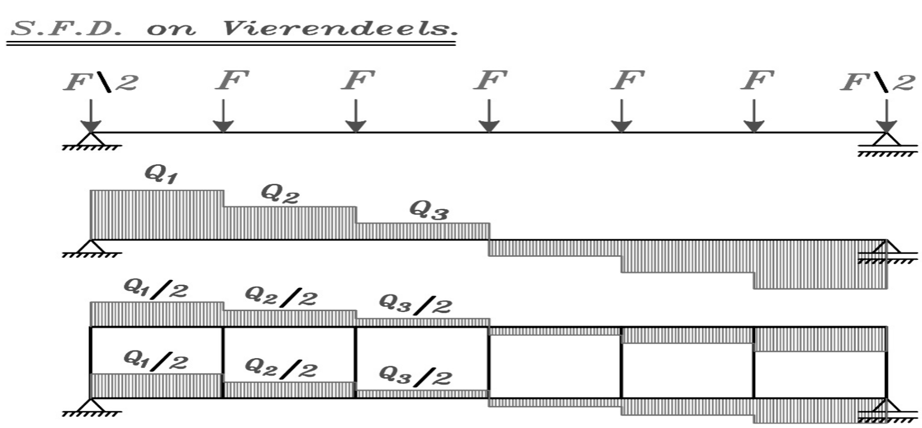


Figure 3.10: One-way slabs carry on Vierendeel.

Reff: Yasser El-leathy 2016, Vierendeel.



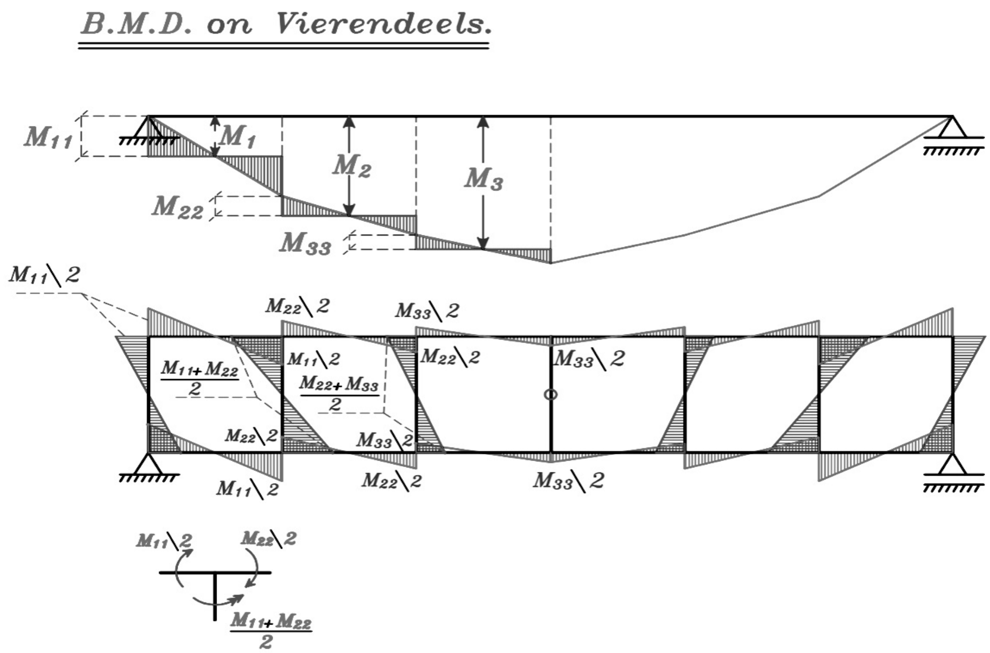


Figure 3.11: Bending moment and shear force diagrams.

Reff: Yasser El-leathy 2016, Vierendeel.

3.7.2. Type two

In this case the vierenedeel as shown the **Figure 3.12** fixed in the one end and cantilever in another side and carry one way slabs. **Figure 3.13** explains how to draw shear force and bending moment diagrams.

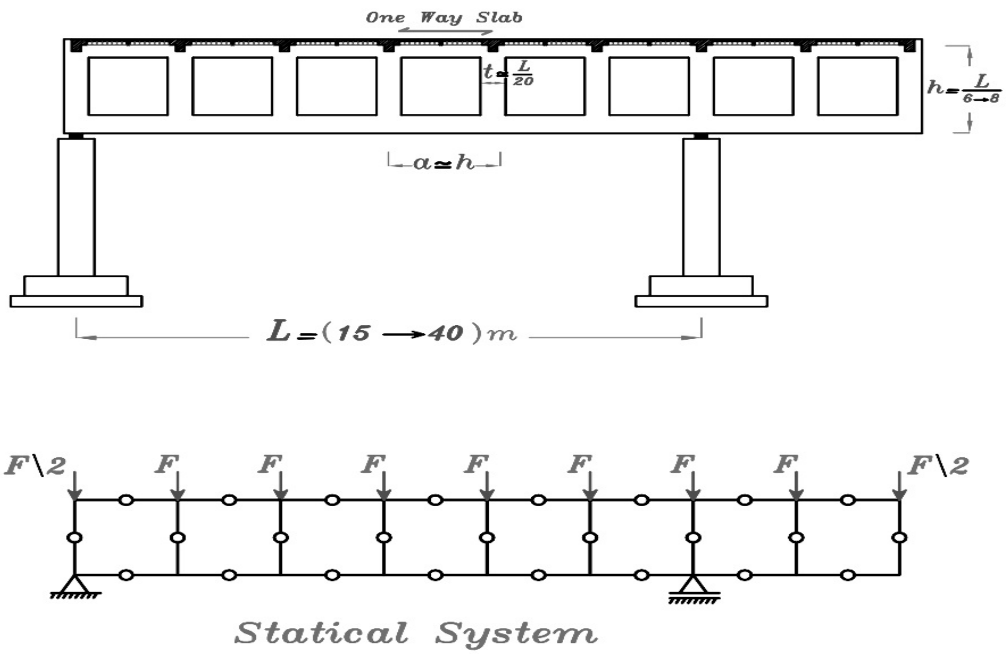
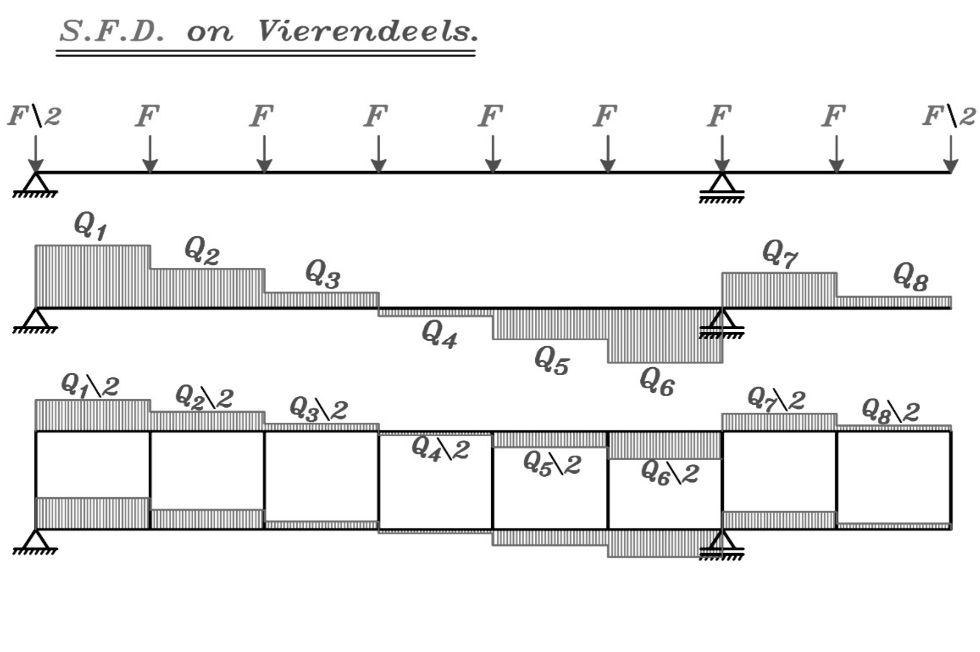


Figure 3.12: Vierenedeel with cantilever in one side.

Reff: Yasser El-leathy 2016, Vierendeel.



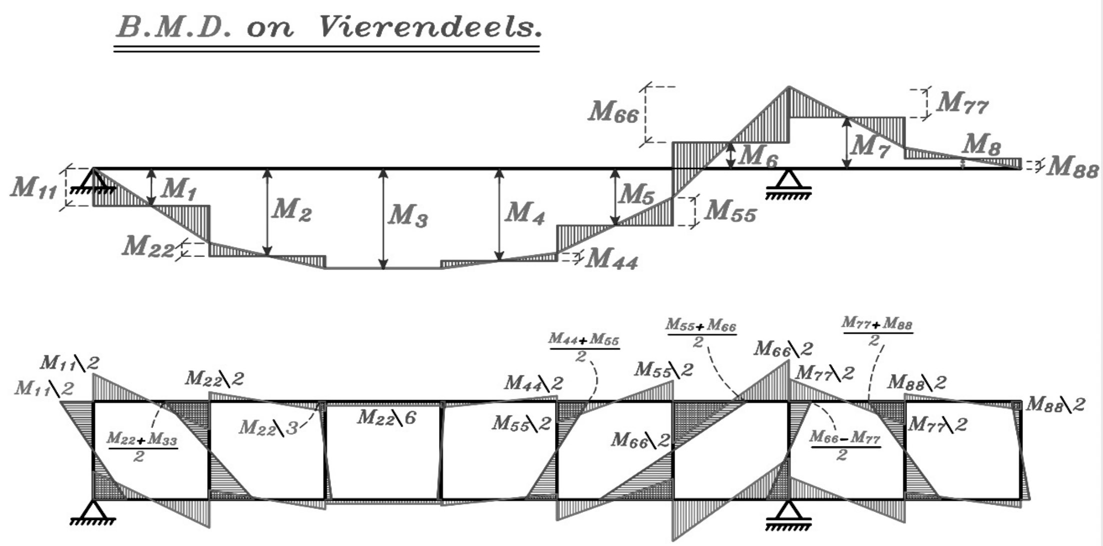


Figure 3.13: Bending moment and shear force diagrams.

Reff: Yasser El-leathy 2016, Vierendeel.

3.6.3 Type Three

In this case the vierenedeel as shown the **Figure 3.14** cantilever in two sides and carry one way slabs**. Figure 3.15** explains how to draw shear force and bending moment diagrams.

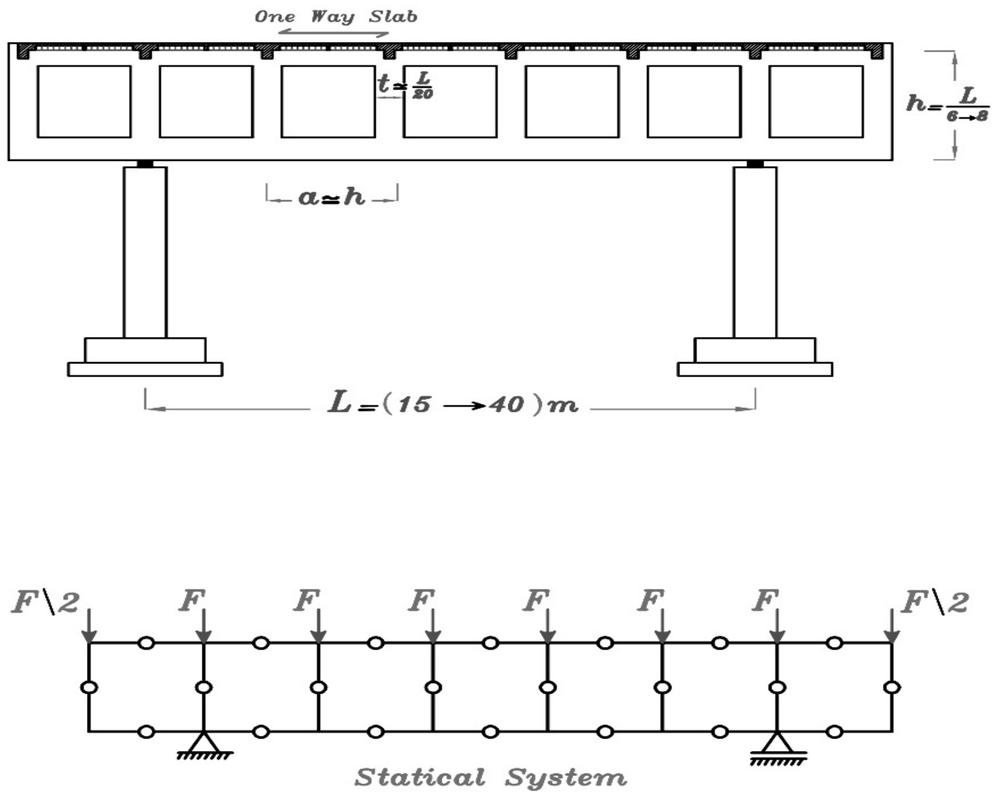
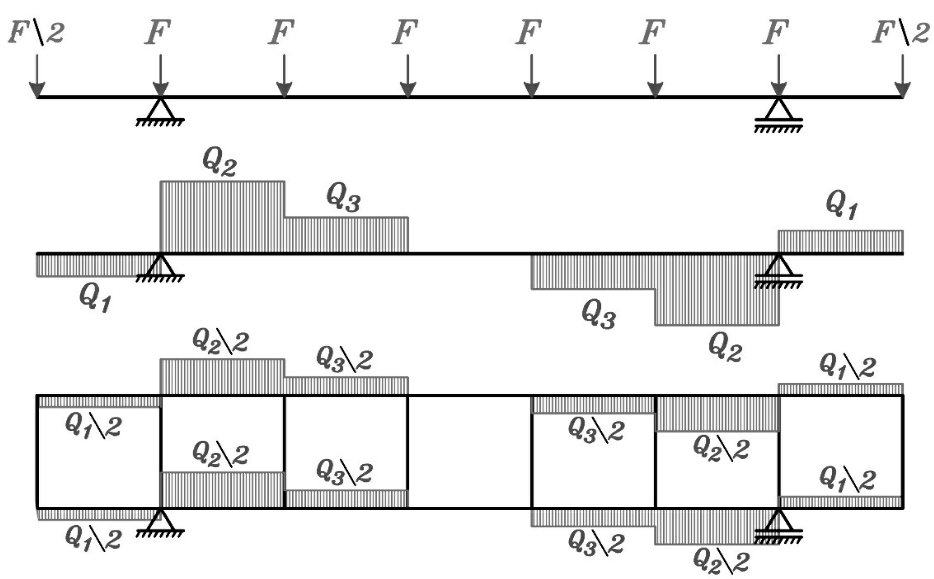


Figure 3.14: Vierenedeel with cantilever in two sides.

Reff: Yasser El-leathy 2016, Vierendeel.

S.F.D. on Vierendeels.



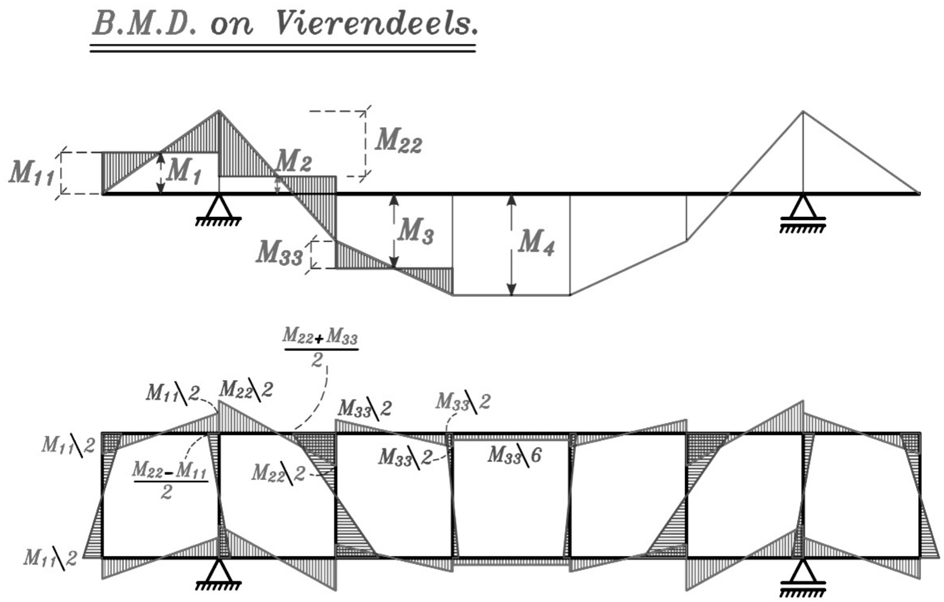


Figure 3.15: Bending moment and shear force diagrams.
Reff: Yasser El-leathy 2016, Vierendeel.

3.8. Short brief about computer aided analysis

With the progress in structure engineering in all types of engineering, electrical, mechanical, etc. and so on there appeared computer programming for multi uses like analysis, design, graphics, mapping and other kind of engineering parts. Moreover, from 1930 or before Second World War engineers managed to solve the problems complicated sciences with avoiding mistakes in calculations and provide short time to make decision. Also, briefing of procedures of analysis and design, which may help engineers to compress the stages of projects.

Structural programs are used for two main targets in design process. The first one is to make procedural programming that enables engineers to shorten the time of calculations in a little time by using of CAD features and to minimize the design time. The second step to use computer Intelligence techniques selection and decision making stages of the design process.

Structural programs, which use CAD techniques in their process had a wide spread in engineering fields that for simplified uses in steps and learning. Also, powerful of results had merits in hand out sheet for engineers. A famous program is STAAD PRO, ETABS, SAPS, SAFE, PROKON and many programs which deferent from country to another depending on standards codes, type of analysis method, units and output of presentation or outlook for interface of the program.

The researcher used SAP2000 v.18 and ROBOT Structural program which are familiar in engineering fields in SUDAN, easy to learn it and the researcher has an experience in this program.

The uses of structural program mainly not limit in deal with techniques of this types of program but moreover to enables with different engineering theorems from understanding elasticity, plasticity, finite element method passing to static and dynamic analysis, finally to the standards codes, units, materials and proprieties of the materials.

3.7.1 Structural Analysis Program (SAP 2000 V.18)

This program is one of the best programs in the field of analysis of construction and most elements prevalent in the world, it is production company CSI in California and is one of the most powerful used programs in this field in terms of dealing with input and output in the graphical easy and pass the structure of the program drawing AUTOCAD and pass the results to design programs to EXCEL and other database programs.

3.8.1.1. Type of structures elements analysis by SAP 2000

Figure 3.16: Type of structures elements analysis by SAP 2000.

3.7.1.2. Steps of modeling and analysis and show results in SAP 2000

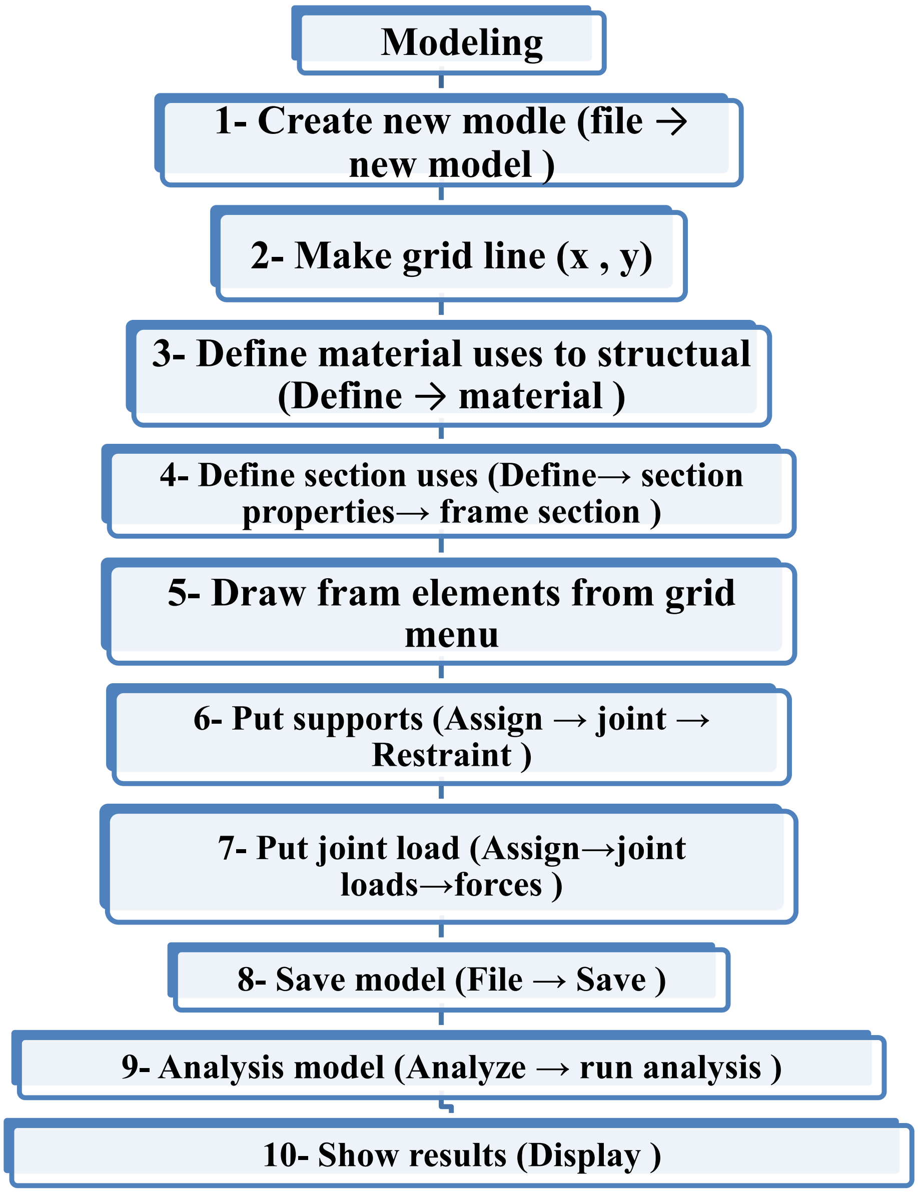


Figure 3.17: Steps of modeling, analysis and results in SAP 2000.

3.8. Robot Structural analysis

This program is one of the best programs in the field of analysis of construction and most elements prevalent in the world; it is production company AUTODISK,

3.8.1. Type of structures elements analysis by robot structural 2015

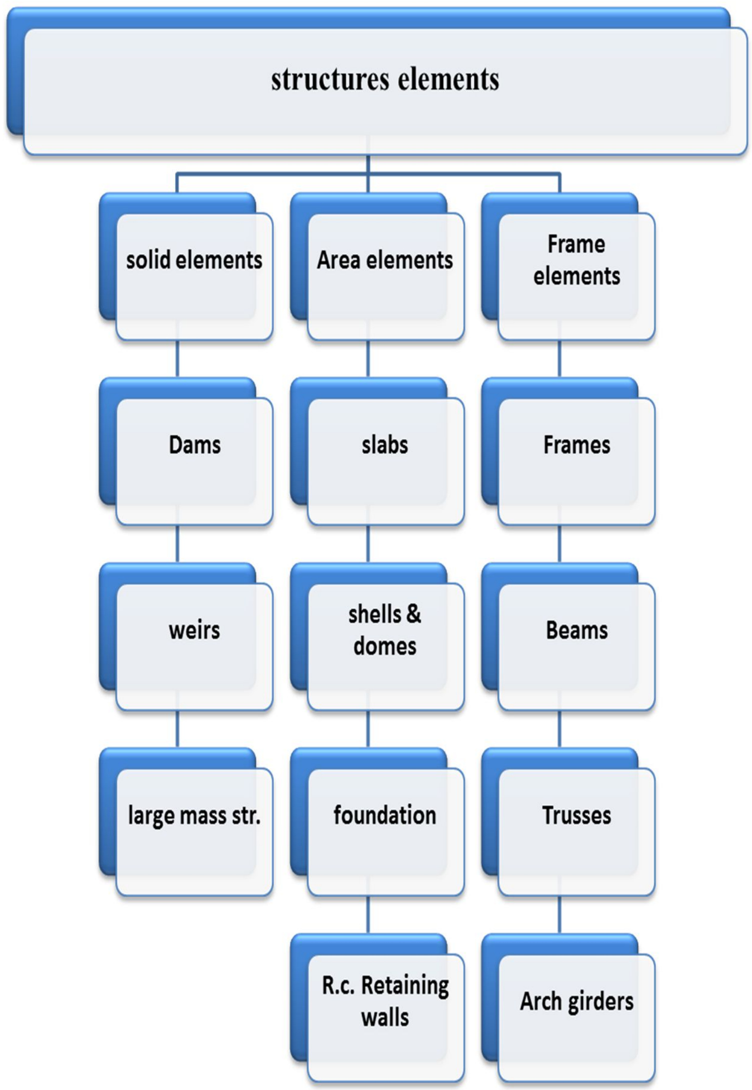


Figure 3.18: Type of structures elements analysis by robot structural.

3.8.2. Steps of modeling and analysis and show results in robot structural

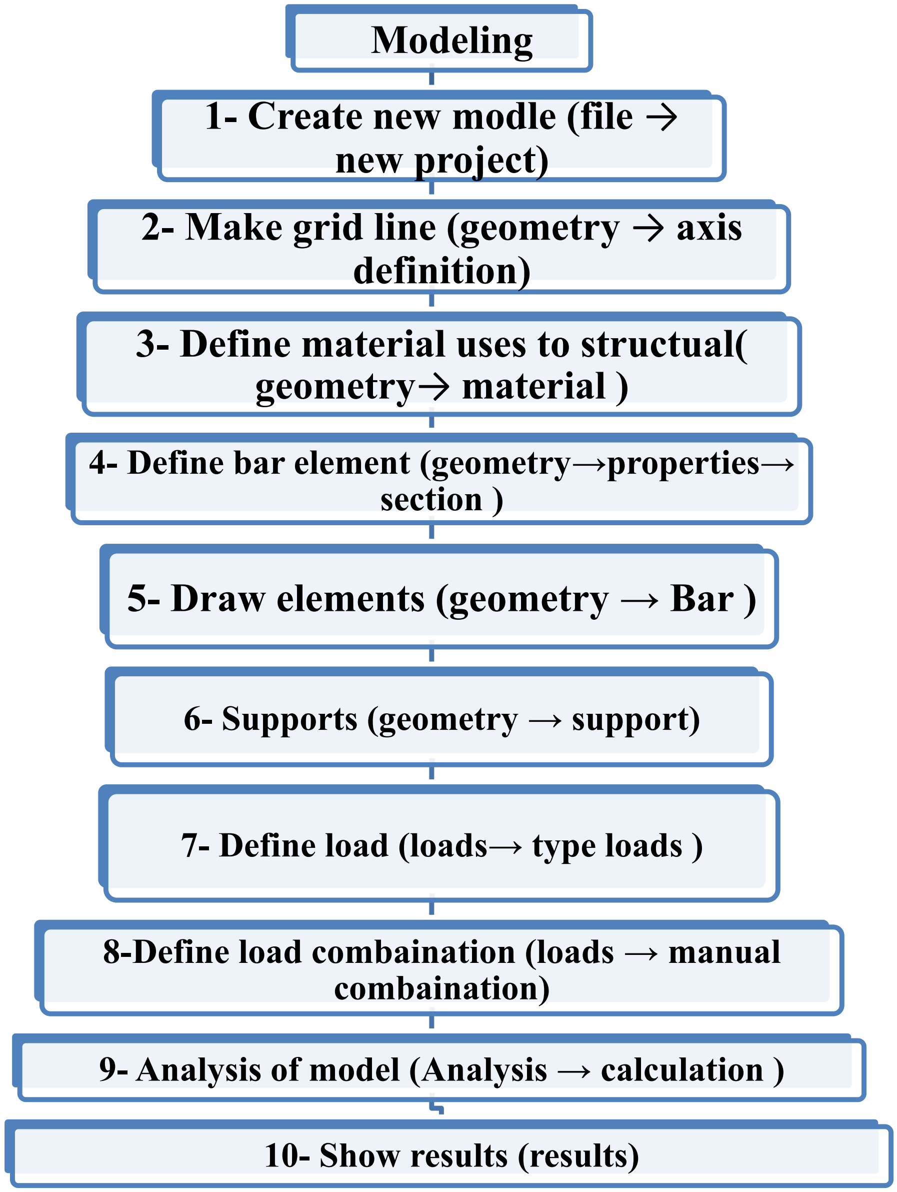


Figure 3.19: Steps of modeling and analysis and show results in robot st 2015.

3.9. The case study

With the great development in the various fields of operation and the need to exploit large areas, which necessitates the development in the field of structural engineering. This study comes in which a building was taken with an area (20x25) of 5 floors and the application of the vierenedeel on the ground floor with the floor stripped from the inner columns. To exploit the internal area. Three models were selected for vierenedeel and applied loads to calculate the internal strengths to choose the most suitable and the most economical.

Figure 3.20 shows a layout of a building of an area 20*25 m^2.

- The building consists of ground floor and five typical floors.
- The interior columns are removed at the ground floor.
- The total equivalent working loads is 12 kN/m^2

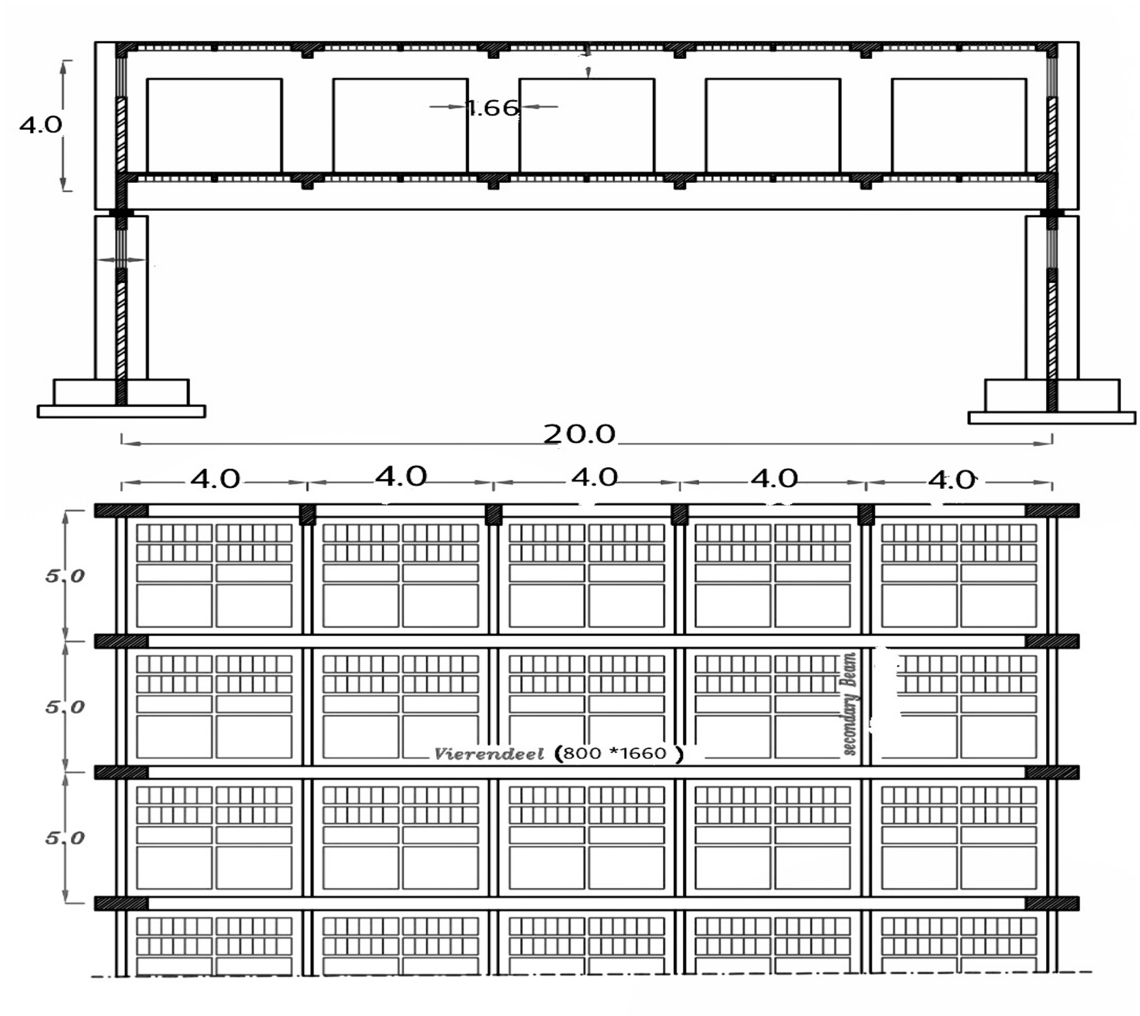


Figure 3.20: Vierenedeel layout 1.

CHAPTER FOUR

ANALYSIS OF RESULTS AND DISCUSSION

4.1. Vierenedeel calculations

- Length of vierenedeel (L) = 20 m
- Height of vierenedeel (h)= L /6 = 20 / 6 = 3.33 m

  (Take h = 4 m)

  a = h = 4 m

- Number of vierenedeel = L / h = 20 / 4 = 5
- Thickness of vierendeel (t_v) = L /(10 - 12) use L/12 = 20/ 12 = 1.66 m
- Thickness of column (t_c) = Thickness of vierendeel (t_v) = 1.66 m
- Assume b = 0.8 m
- Take the main supporting element vierenedeel (0.8 * 1.66)

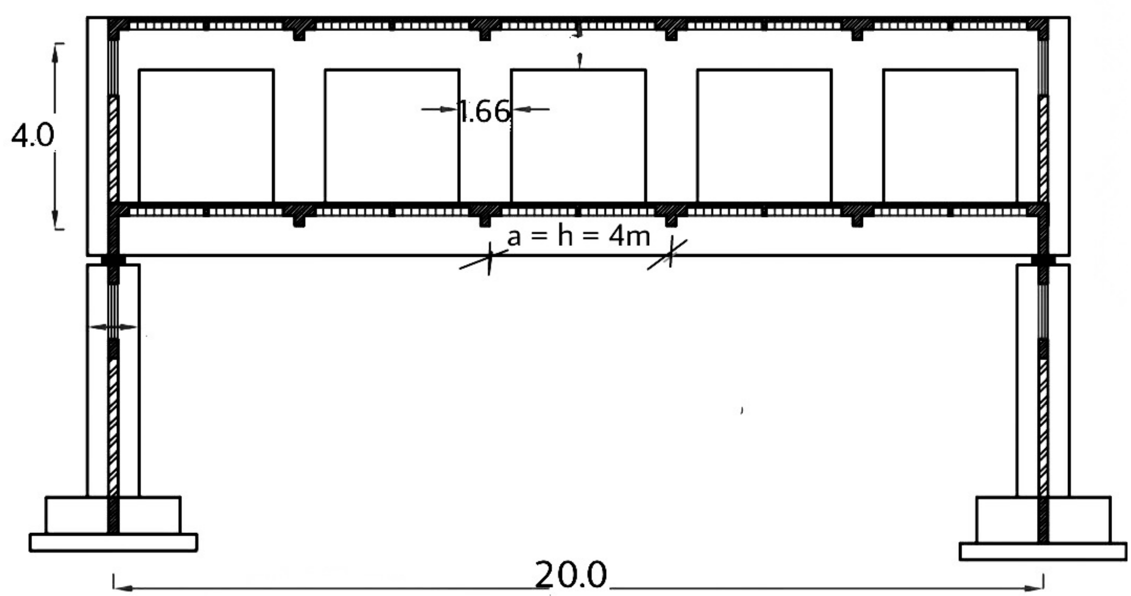


Figure 4.1 Vierendeel Layout.

- The total equivalent working load is 12 kN / m^2
- Wav (u.l) = 12 * 1.5 = 18 kN/m^2
- Total load for one floor = Wav * floor area

  18 * 20 * 25 = 9000 kN

  - Total load for the building = load of one floor * No of floor

(Additional weight of ground floor)

9000 * 6 = 54000 kN

  - Total load on one vierenedeel = Total load for the building / No. of vierendeel

(Distribution the total load on number of vierenedeel, but assumption the first and the last system carry half load just)

54000 / 5 = 10800 KN

Load per joint of the vierenedeel = load on one vierenedeel / No. of joints

F = 10800 / 5 = 2160 kN

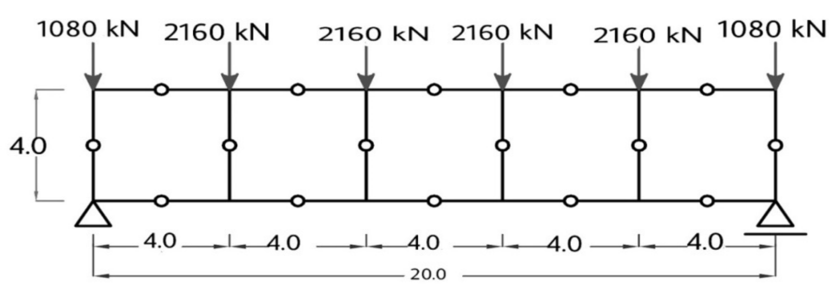


Figure 4.2: Statically system of vierenedeel.

4.2. Manual Analysis using approximate method

Sum of vertical load = sum of horizontal load

$R_1 + R_2 = 10800$ ………. (1)

Take moment @ R_1:-

$-1080 * 20 + R_2 * 20 - 2160 * (16 + 12 + 8 + 4) = 0$

$R_2 = 108000 / 20 = 5400$ KN

From equation (1):-

$R_1 = 10800 - R_2 = 10800 - 5400 = 5400$ kN

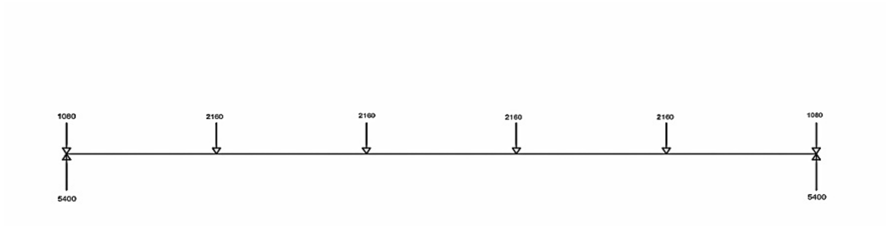


Figure 4.3: Reactions on vierenedeel.

Shear Force in vierenedeel was calculated as follows:

- $Q_1 = R_1 - F / 2 = 5400 - 1080 = 4320$
- $Q_2 = Q_1 - F = 4320 - 2160 = 2160$
- $Q_3 = Q_2 - F = 2160 - 2160 = 0$

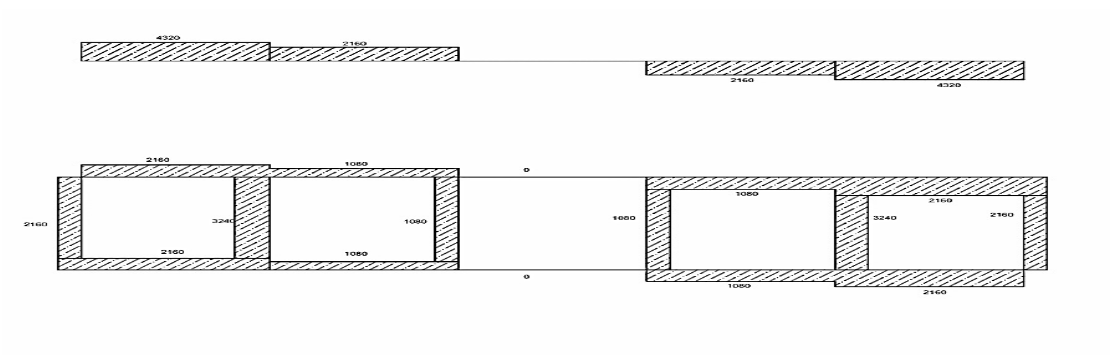


Figure 4.4: Shear forces diagram for model (1).

The following calculated moments in supports and middle were shown in **Figure 4.5**.

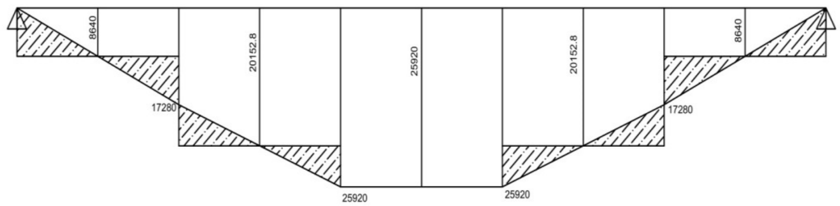


Figure 4.5: Moment in vierenedeel using approximate method.

From **Figure (4.5)**

M_1 = (5400*2) – (1080*2) = 8640 kN.m

M_2 = (5400*5.33) – (1080*5.33) – (2160*1.33) = 20152.8 kN.m

M_3 = (5400*10) – (1080*10) – (2160*6) – (2160*2) = 25920 kN.m

M_1 = M_{11} = 8640 kN.m

$M_{22\,(1)}$ = 20152.8 – 17280 = 2872.8 kN.m

$M_{22\,(2)}$ = 25920 - 20152.8= 5767.2 kN.m

M_{11} / 2 = 8640 / 2 = 4320 kN.m

$M_{22\,(1)}$ / 2 = 2872.8 / 2 = 1436.4 kN.m

$M_{22\,(2)}$ / 2 = 5767.2/2 = 2883.6 kN.m

M_{11} + M_{22} / 2 = 8640 + 2872.8 / 2 = 5756.4 kN.m

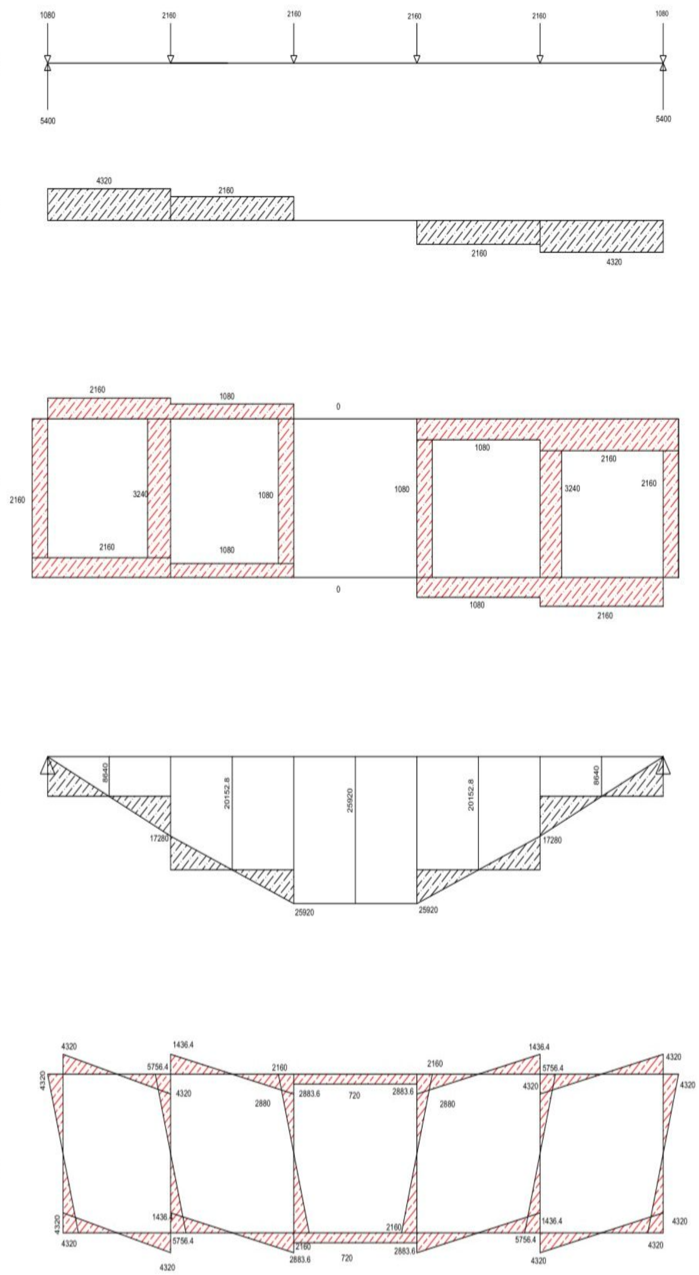


Figure 4.6: Final diagrams for model (1): (a) Reactions; (b) &(c) Shear forces diagram. (d) Moments diagram; (e) Final moment in vierendeel.

The same calculation in all member and other two vierenedeels were carried out as shown in **Figures 4.7- 4.8.**

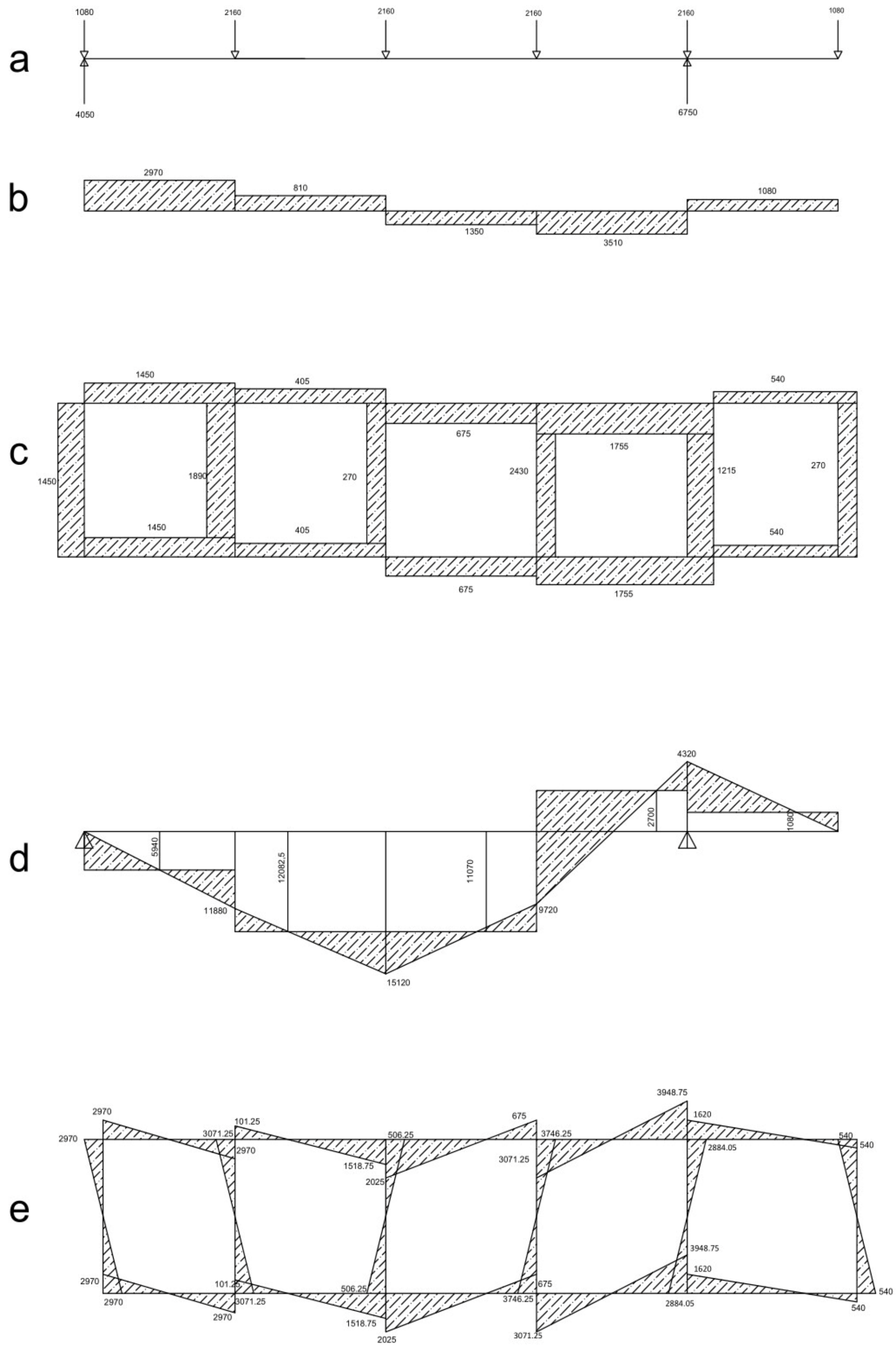


Figure 4.7: Final diagrams for model (2): (a) Reactions; (b) &(c) Shear forces diagram. (d) Moments diagram; (e) Final moment in vierendeel.

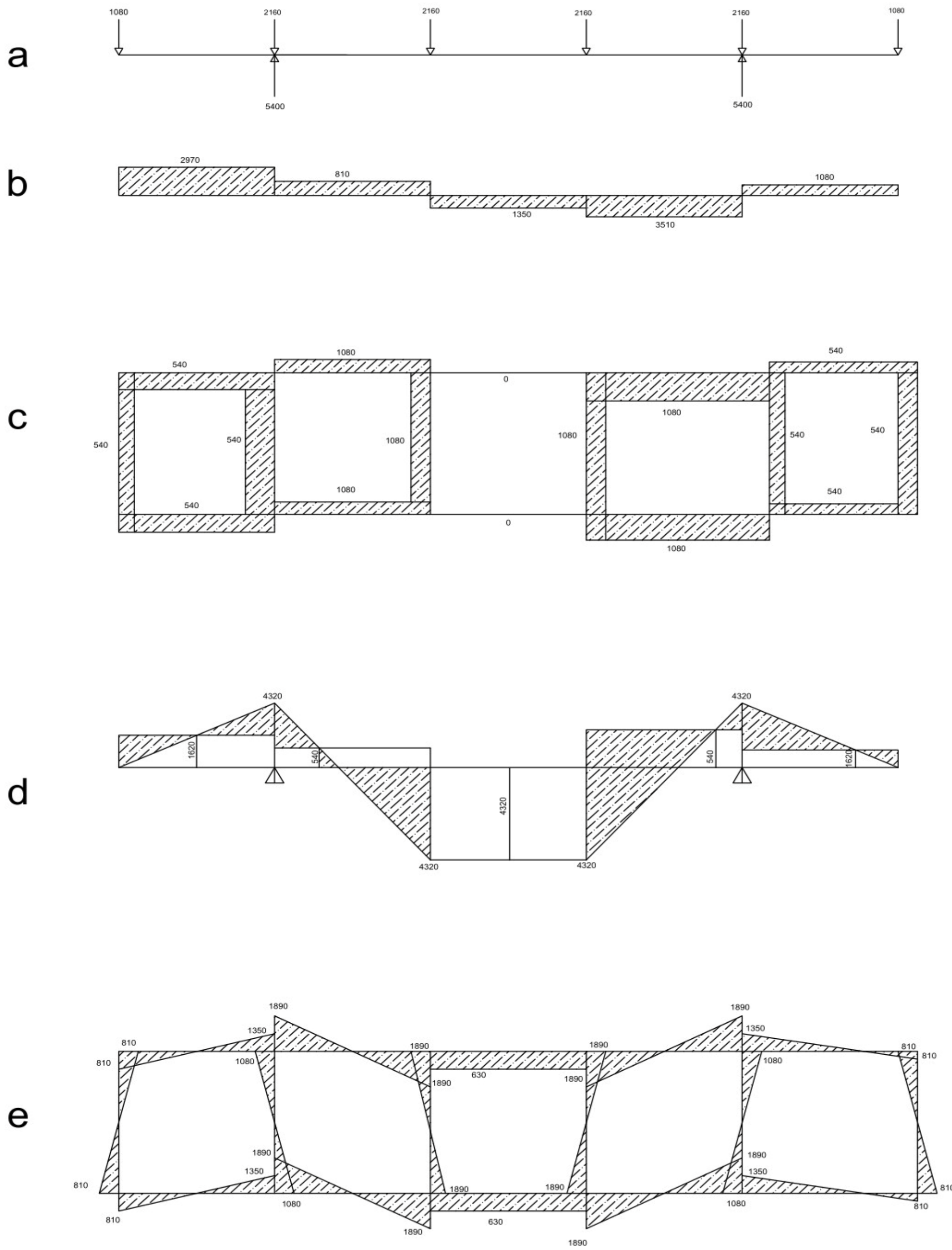


Figure 4.8: Final diagrams for model (3): (a) Reactions; (b) &(c) Shear forces diagram. (d) Moments diagram; (e) Final moment in vierendeel.

4.3. Analysis using SAP 2000 v.18

In this part, results obtained using **SAP 2000** were reviewed. The **Figures 4.9-4.17** below were described the values of shear forces and moments for the three type of vierenedeels.

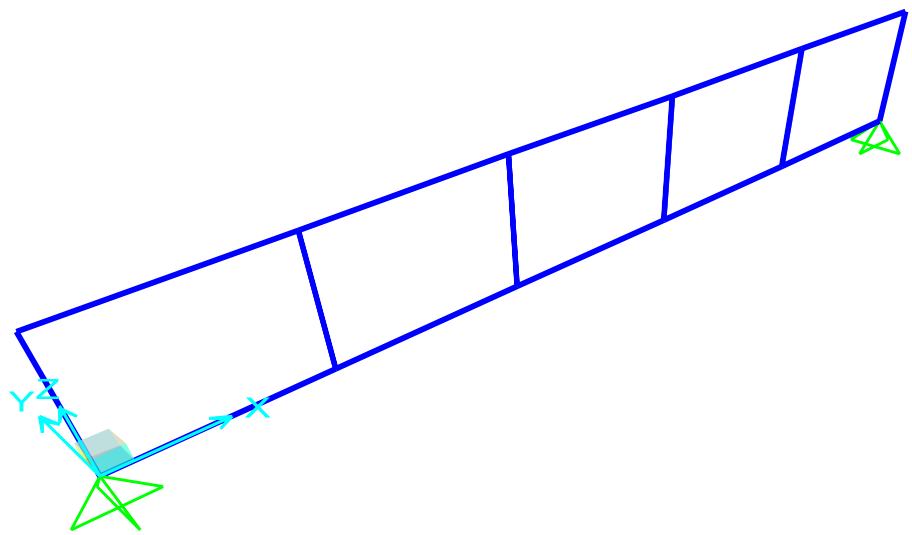


Figure 4.9:3D vierendeel model (1).

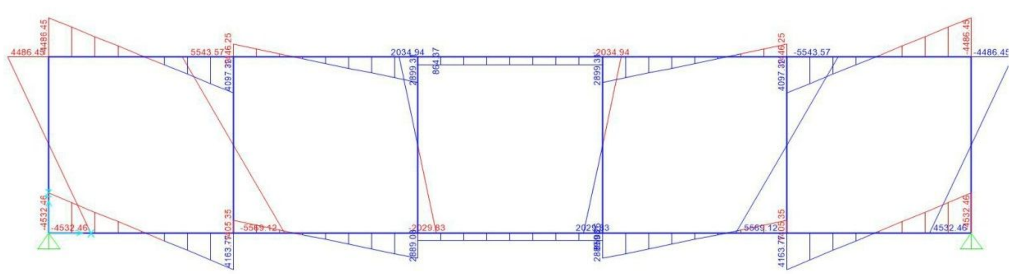


Figure 4.10: Bending moments diagram for vierenedeel model (1) using SAP 2000.

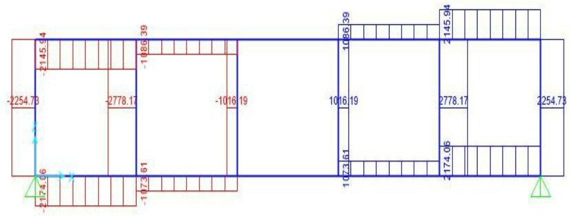


Figure 4.11: Shear forces diagram for vierendeel model (1) using SAP 2000.

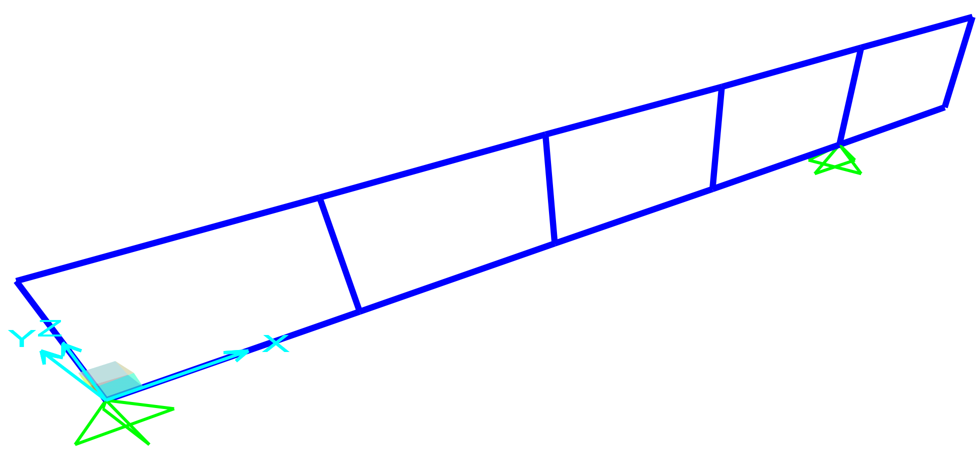


Figure 4.12: 3D vierendeel model (2).

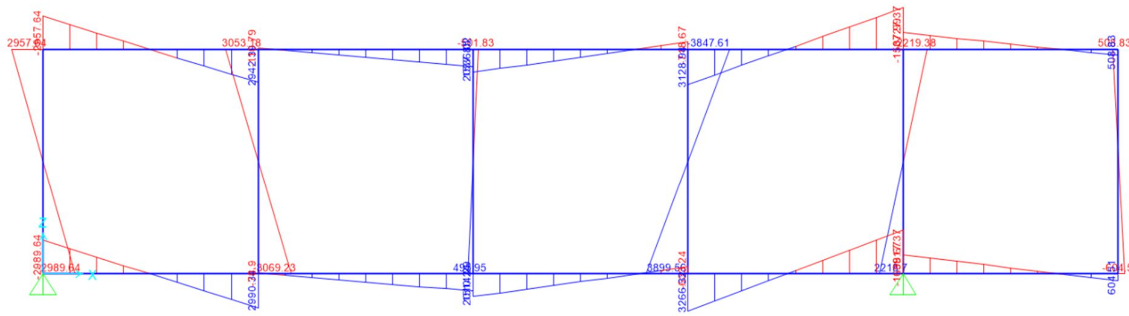


Figure 4.13: Bending moments diagram for vierendeel model (2) using SAP 2000.

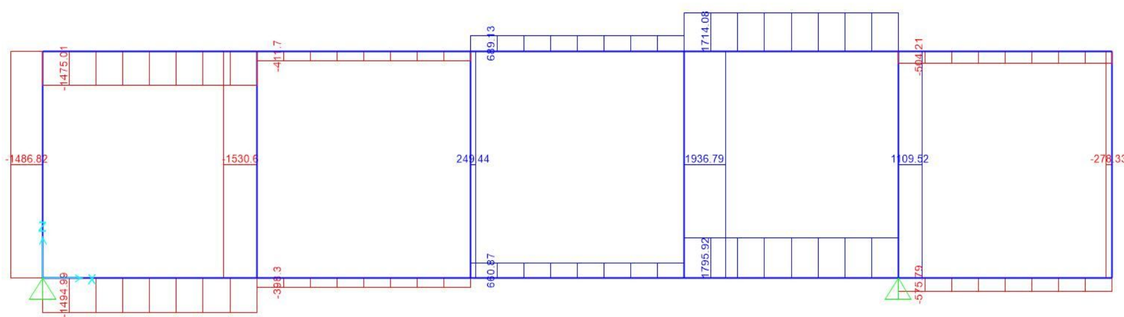


Figure 4.14: Shear forces diagram for vierendeel model (2) using SAP 2000.

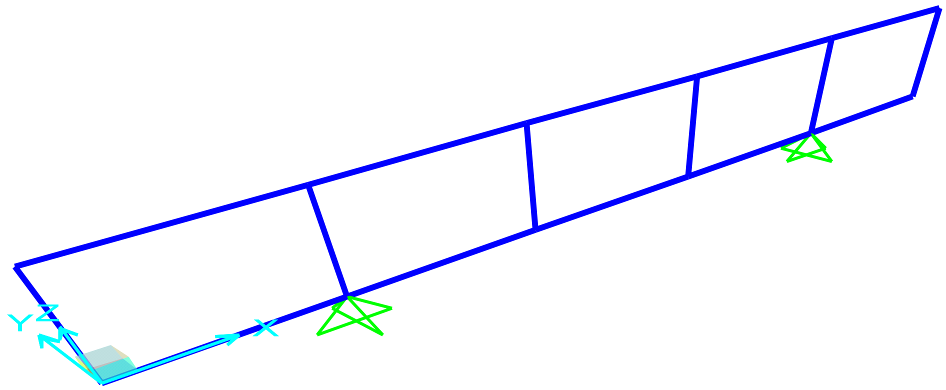


Figure 4.15: 3D vierendeel Model (3).

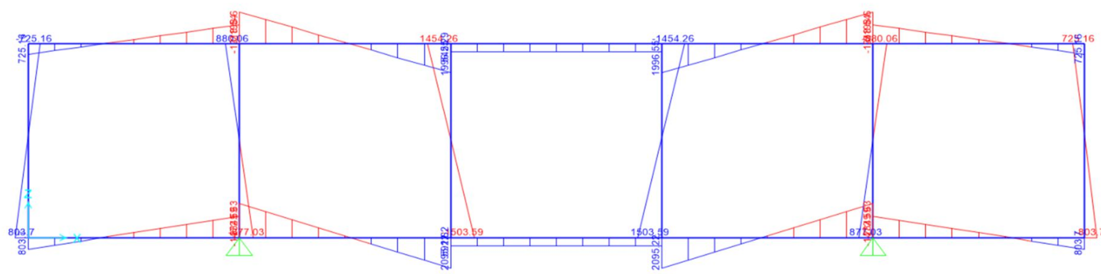


Figure 4.16: Bending moments diagram for vierendeel model (3) using SAP 2000.

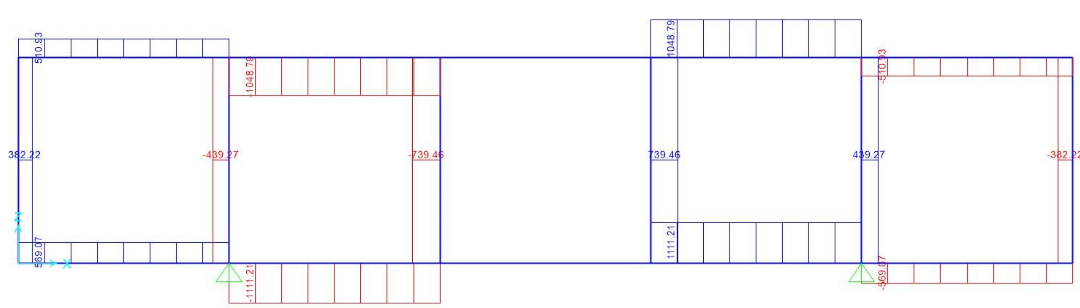


Figure 4.17: Shear forces diagram for vierendeel model (3) using SAP 2000.

4.4. Analysis using Robot structural 2015

In this part, results obtained using **SAP 2000** were reviewed. The **Figures 4.18-4.23** below were described the values of shear forces and moments for the three type of vierendeels.

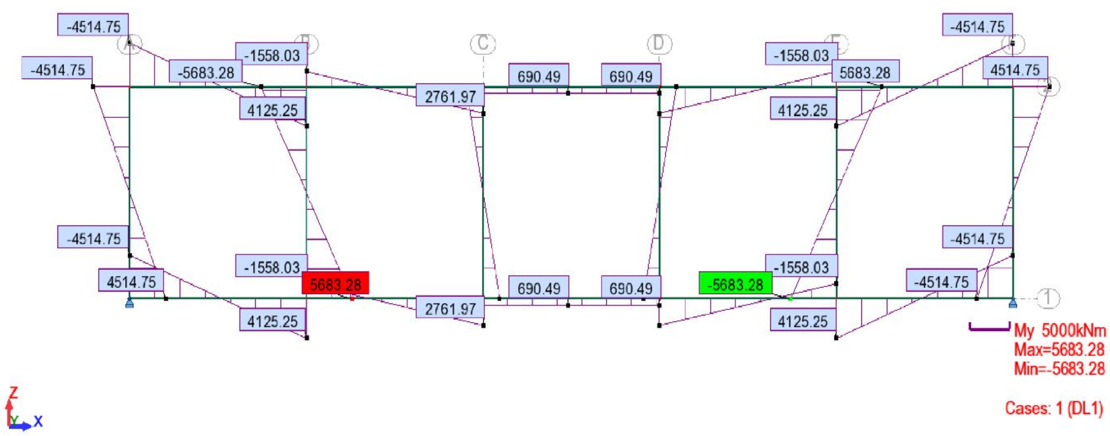


Figure 4.18: Bending moments diagram for vierendeel model (1) using Robot 2015.

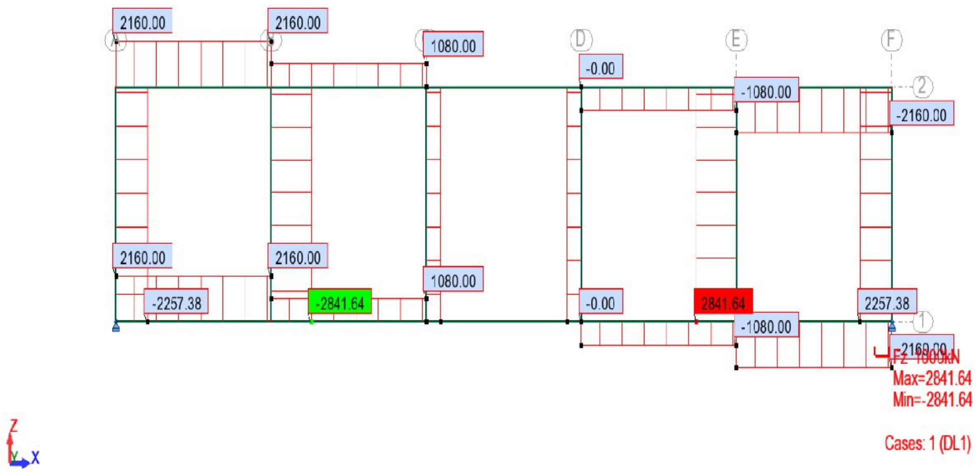


Figure 4.19: Shear forces diagram for vierendeel model (1) using Robot 2015

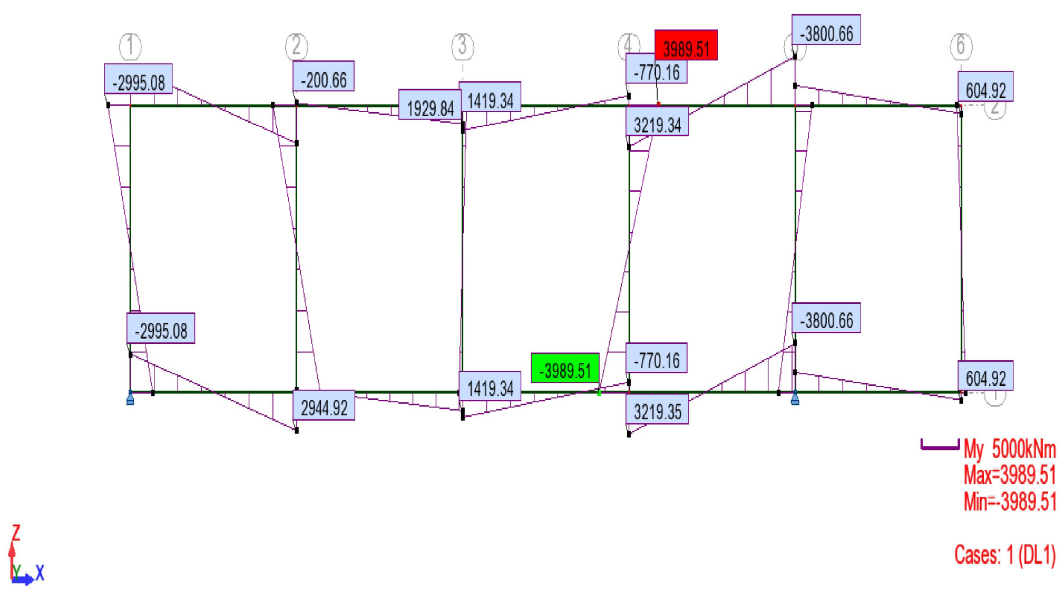


Figure 4.20: Bending moments diagram for vierendeel model (2) using Robot 2015.

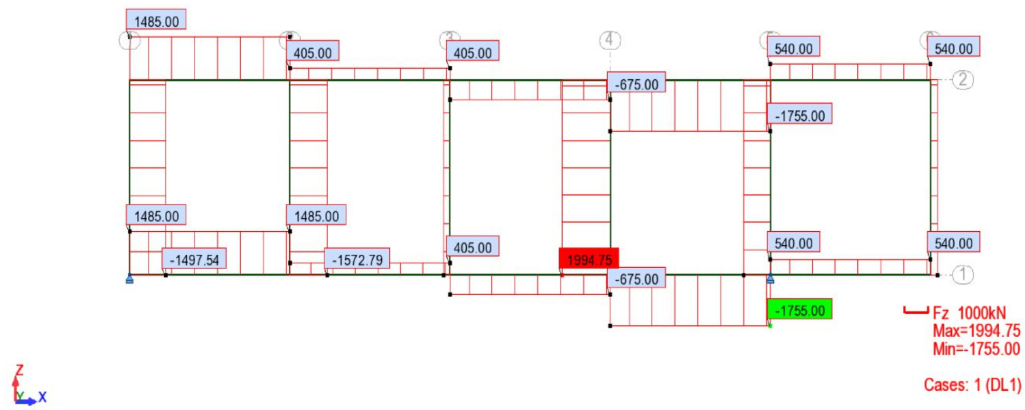


Figure 4.21: Shear forces diagram for vierendeel model (2) using Robot 2015.

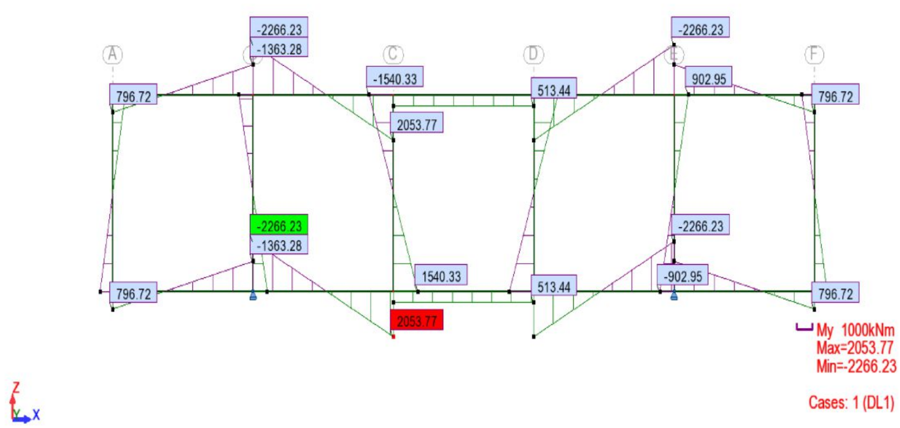


Figure 4.22: Bending moments diagram for vierendeel model (3) using Robot 2015.

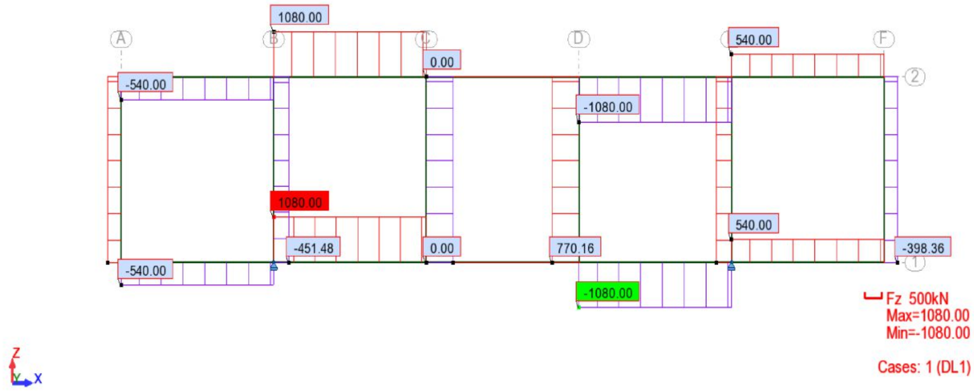


Figure 4.23: Shear forces diagram for vierendeel model (3) using Robot 2015.

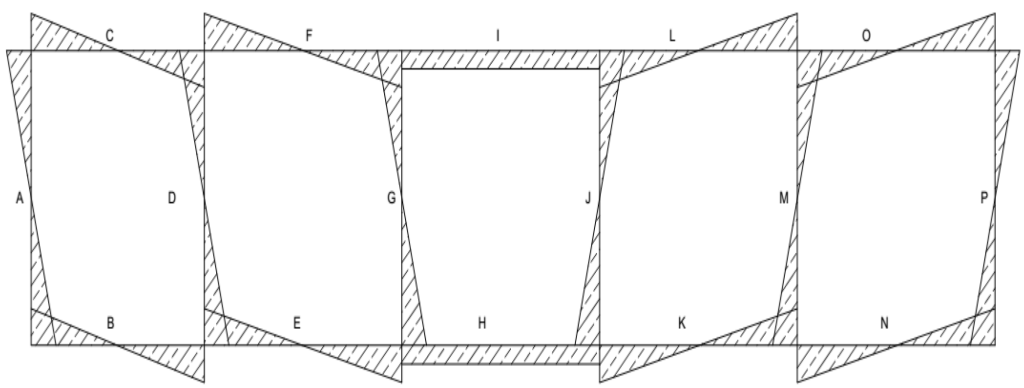


Figure 4.24: Members of vierendeel.

Table 4.1: Comparison of bending moments using approximate method, SAP 2000 and Robot 2015 for vierendeel model (1).

Member ID	Joint ID	Approximate method	SAP2000	Difference between Approx. & SAP2000 (%)	Robot ST 2015	Difference between Approx. & Robot (%)
A	1	4320	4486	4	4518	5
	2	-4320	-4532	5	-4125	5
B	1	-4320	-4532	5	-4515	5
	2	4320	4164	4	4125	5
C	1	-4320	-4320	0	-4515	5
	2	4320	4320	0	4125	5
D	1	5756	5756	0	5683	1
	2	-5756	-5756	0	-5683	1
E	1	-1436	-1436	0	-1558	8
	2	2884	2884	0	2762	4
F	1	-1436	-1446	1	-1558	8
	2	2884	2899	1	2762	4
G	1	2160	2035	6	2071	4
	2	-2160	-2030	6	-2071	4
H	1	720	864	20	690	4
I	1	720	859	19	690	4
J	1	-2160	-2035	6	-2071	4
	2	2160	2030	6	2071	4
K	1	2884	2889	0	2762	4
	2	-1436	-1405	2	1558	8
L	1	2884	2889	0	2762	4
	2	-1436	-1405	2	-1558	8
M	1	-5756	-5544	4	-5683	1
	2	5756	5569	3	5683	1
N	1	4320	4532	5	4515	5
	2	-4320	-4164	4	-4125	5
O	1	4320	4486	4	4515	5
	2	-4320	-4097	5	-4125	5
P	1	-4320	-4532	5	-4518	5
	2	4320	4164	4	4125	5

Table 4.2: Comparison of shear forces using approximate method, SAP 2000 and Robot 2015 for vierendeel model (1).

Member ID	Approximate method	SAP2000	Difference between Approx. & SAP2000 (%)	Robot ST 2015	Difference between Approx. & Robot (%)
A	2160	-2255	4	-2257	5
B	2160	-2174	1	-2160	0
C	2160	-2146	1	-2160	0
D	3240	-2778	14	-2842	12
E	1080	-1074	1	-1080	0
F	1080	-1086	1	-1080	0
G	1080	-1016	6	-1036	4
H	0	0	0	0	0
I	0	0	0	0	0
J	-1080	1016	6	1036	4
K	-1080	1074	1	1080	0
L	-1080	1086	1	1080	0
M	-3240	2778	14	2842	12
N	-2160	2174	1	2160	0
O	-2160	2146	1	2160	0
P	-2160	2255	4	2257	5

Table 4.3: Comparison of bending moments using approximate method, SAP 2000 and Robot 2015 for vierendeel model (2).

Member ID	Joint ID	Approximate method	SAP2000	Difference between Approx. & SAP2000 (%)	Robot ST 2015	Difference between Approx. & Robot (%)
A	1	-2970	-2958	0	-2995	1
	2	-2970	-2990	1	2995	1
B	1	-2970	-2990	1	-2995	1
	2	2970	2990	1	2945	1
C	1	-2970	-2958	0	-2995	1
	2	2970	2942	1	2944	1
D	1	-3071	-3053	1	-3146	2
	2	-3071	-3069	0	-31456	2
E	1	-101	-79	22	-201	98
	2	1519	1514	0	1419	7
F	1	-101	-111	9	-201	98
	2	1519	1536	1	1419	7
G	1	-506	-502	1	-510	1
	2	506	496	2	510	1
H	1	2025	2010	1	1930	5
	2	-675	-633	6	-770	14
I	1	2025	2038	1	1930	5
	2	-675	-719	6	-770	14
J	1	3746	3848	3	3990	7
	2	3746	3900	4	3990	7
K	1	3071	3266	6	3219	5
	2	-3949	-3917	1	-3881	2
L	1	3071	3129	2	3219	5
	2	-3949	-3727	6	-3881	2
M	1	-2884	-2219	23	-2246	22
	2	-2884	-2219	23	-2246	22
N	1	-1620	-1699	5	-1555	4
	2	540	605	12	605	12
O	1	-1620	-1508	7	-1555	4
	2	540	509	6	605	12
P	1	-540	-509	6	-605	12
	2	-540	-605	12	-604.92	12

Table 4.4: Comparison of shear forces using approximate method, SAP 2000 and Robot 2015 for vierendeel model (2).

Member ID	Approximate method	SAP2000	Difference between Approx. & SAP2000 (%)	Robot ST 2015	Difference between Approx. & Robot (%)
A	-1485	-1487	0	-1498	0
B	-1485	-1500	1	-1498	1
C	-1485	-1475	1	-1485	0
D	-1590	-1531	19	-1573	17
E	-405	-398	2	-405	0
F	-405	-412	2	-405	0
G	270	249	8	255	6
H	675	661	2	675	0
I	675	689	2	675	0
J	2430	1937	17	1995	15
K	1755	1796	2	1755	0
L	1755	1714	2	1755	0
M	1215	1110	9	1123	8
N	540	576	7	540	0
O	540	504	7	540	0
P	270	275	2	302	12

Table 4.5: Comparison of bending moments using approximate method, SAP 2000 and Robot 2015 for vierendeel model (3).

Member ID	Joint ID	Approximate method	SAP2000	Difference between Approx. & SAP2000 (%)	Robot ST 2015	Difference between Approx. & Robot (%)
A	1	810	725	10	797	2
	2	810	804	1	797	2
B	1	810	804	1	797	2
	2	-1350	-1473	9	-1363	1
C	1	810	725	11	797	2
	2	-1350	-1319	2	-1363	1
D	1	1080	880	19	903	16
	2	-1080	-877	19	-903	16
E	1	-1890	-2350	24	-2266	20
	2	1890	2095	11	2054	9
F	1	-1890	-2199	16	-2266	20
	2	1890	1997	6	2054	9
G	1	-1890	-1454	23	-1540	19
	2	-1890	-1504	20	-1540	19
H	1	630	592	6	513	19
	2	630	592	6	513	19
I	1	630	542	14	513	19
	2	630	542	14	513	19
J	1	1890	1454	23	1540	19
	2	1890	1504	20	1540	19
K	1	1890	2095	11	2054	9
	2	-1890	-2350	24	-2266	20
L	1	1890	1997	6	2054	9
	2	-1890	-2199	16	-2266	20
M	1	1080	-880	19	-903	16
	2	1080	877	19	903	16
N	1	-1350	-1473	9	-1363	1
	2	810	804	1	797	2
O	1	-1350	-1473	9	-1363	1
	2	810	804	0.87	797	2
P	1	-810	-725	10	-797	2
	2	-810	-804	1	-7967	2

Table 4.6: Comparison of shear forces using approximate method, SAP 2000 and Robot 2015 for vierendeel model (3).

Member ID	Approximate method	SAP2000	Difference between Approx. & 2000 (%)	Robot ST 2015	Difference between Approx. & Robot (%)
A	540	382	29	398	26
B	540	570	6	540	0
C	540	511	5	540	0
D	-540	-439	19	-451	16
E	-1080	-1111	3	-1080	0
F	-1080	-1049	3	-1080	0
G	-1080	-739	32	-770	29
H	0	0	0	0	0
I	0	0	0	0	0
J	1080	739	32	770	29
K	1080	1111	3	1080	0
L	1080	1049	3	1080	0
M	540	439	19	451	16
N	-540	-570	5.5	-540	0
O	-540	- 511	5	540	0
P	-540	-382	29	-398	26

In this section, all results of shear forces and moments diagrams were obtained using SAP 2000 and Robot st 2015 as shown in **Figures 4.9 – 4.23**. The results of moments and shear forces for all vierenedeel models were shown **Tables 4.1 – 4.6.**

In order to make a comparison between the three mentioned vierendeel models, it was taken the members of maximum bending moments and shear forces as shown in **Table 4.7**. This will help to select the more effective system of vierendeel frame to optimize the design of members.

Table 4.7: Member of maximum bending moments and shear forces using approximate method, SAP 2000 and Robot st 2015for the three vierendeel model.

Vierendeel model No.	Members	Maximum moment (kN.m)		Maximum shear force (kN)
1	D, M	Approx.	5756	3240
		SAP2000	5756	2778
		Robot st	5663	2842
2	K, L	Approx.	3949	1755
		SAP2000	3917	1796
		Robot st	3881	1755
3	E, K	Approx.	1890	1080
		SAP2000	2095	1111
		Robot st	2054	1080

4.5. Discussion of results

Analysis of vierenedeel models were carried out using approximate method and computer programs (SAP 2000 and Robot st 2015). The comparison of results between approximate method and computer programs (SAP 2000 and Robot st 2015) were presented for selected three models of vierenedeel to show the difference in shear forces and bending moments. The approximate method was taken as basic comparison.

1- For vierenedeel model (l), it was noticed that bending moments using SAP 2000 increased about (0 – 20%) and by Robot 2015 about (1.3 – 8.5%) in comparison with approximate method. It was also found that an increasing in shear forces by SAP 2000 about (0 - 14%) and by Robot 2015 about (0-12%) in comparison with approximate method.
2- For vierenedeel model (2), it was observed that bending moments using SAP 2000 increased about (0.1 – 23%) and by Robot 2015 about (0.8 – 22%) in comparison with approximate method. It was also found that an increasing in shear forces by SAP 2000 about (0.1 - 19%) and by Robot 2015 about (0 - 17%) in comparison with approximate method.
3- For vierenedeel model (3), it was found that bending moments using SAP 2000 increased about (0.8 – 24%) and by Robot 2015 about (1 – 20%) in comparison with approximate method. It was also found that an increasing in shear forces by SAP 2000 about (0-32%) and by Robot 2015 about (0-29%) in comparison with approximate method.
4- Form **Table 4.7**, it was shown that the vierendeel model (3) gave minimum values of bending moments and shear forces in comparison with other two models (1) and (2), this because the cantilever action in two sides of vierendeel frame bending moment and shear distribution in all members.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In this study, three models of vierenedeel frame were taken for a residential building of fifth storey with an area (20X25 m2). It was studied under the effect of loading to calculate the values of bending moments and shear forces using approximated method and computer programs (SAP 2000 and Robot st 2015).

The conclusion was summarized as follows:

1- It was found that the maximum values of bending moments and shear forces were in vierenedeel model (1) in members (D&M) as shown in **Table 4.7**.
2- It was found that the minimum values of bending moments and shear forces were in vierenedeel model (3) in members (E&K).
3- It was concluded that vierendeel model (3) was more effective type in comparison with models (1) and (2), this because it led to minimum values of bending moments and shear forces.
4- It was noticed that the approximate method overestimates the values of bending moments and shear forces in comparison with computer programs SAP 2000 and Robot structural 2015. It is preferable to use the computer programs in the analysis of vierendeel frames, because these programs are based of finite element method.

5- Use sap200 for case (1) because the difference of percentage between sap2000 and approximate method.

5.2. Recommendations

Recommendations may be summarized:

1- In order to gain good results so as to minimize errors original issue of computer program must be used.
2- Researcher comments to make studies in vierenedeel model and other structural systems more specialized.
3- This study did not implement the vierenedeel frame in Sudan in details, so more studies in this field may be useful for researchers, the libraries, and engineering sciences`.
4- The designer must allow more alternatives for making decision to select vierenedeel frame crane, moreover he can modify the sections those allowed in the market ,that may done by testing those sections.
5- The engineers must create more studies in this field so as to catch progressing in constructions methods, as while the vierenedeel frames provide large area that can be exploited optimally.
6- In updating technology of computer aided design the company manufactured new issues for all structural analysis and design that may reduce the time of research in coming days; so we advise to enter those programs in the domain of the researches.

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