EVALUATION OF THERMAL SRESSES IN CONTINOUOS CONCRETE BRIDGES

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ABSRACT
This search is mainly concerned with making a comparison between three methods for analyzing continuous concrete bridges, Priestly, Abdul-Ahad and finite elements. Three standard Design temperature distribution, New Zealand, AASHTO and British (5400) were used to analyze the concrete bridges in Baghdad. The analysis of two continues precast prestressed concrete bridges in Baghdad are presented. Another comparison as made between the thermal stresses and the stress associated with dead and live loads. Analytical results indicated that stresses and curvature values are very sensitive to the type of temperature distribution assumed. The suggested analytical models for the bridge can be used to be predict thermal movement and stresses due to any shape of temperature distribution.

الخلاصة

يتعلق هذا البحث بصورة رئيسية بعمل مقارنة بين ثلاث طرق للتحليل الحراري للجسور الخرسانية ذات العتبات المستمرة، طريقة برز تلي، عبد الأحد والعناصر المحددة. ثلاث من المواصفات القياسية للتوزيع الحراري، النيوزلندية، الأمريكية AASHTO والبريطانية رقم 5400 اعتمدت في تحليل الجسور الخرسانية. تم تحليل جسرين مشيدين من الخرسانة المسبقة الجهد والصب في منطقة بغداد، وعمل مقارنة أخرى بين الاجهادات الحرارية والاجهادات نتيجة الأحمال الميتة والحية. أظهرت النتائج التحليلية إن قيم الاجهادات والانحناءات تتأثر بصورة مباشرة بشكل التوزيع الحراري. الموديلات التي تم اقتراحها في هذا البحث يمكن استخدامها لحساب الاجهادات والازاحات الحرارية لأي شكل من التوزيع الحراري.

KEY WORDS
Bridge structures, finite elements, thermal stresses...

INTRODUCTION

General Effect of Temperature on Bridge

Bridge structures are usually subjected to a complex environmental exposure that changes with time. The ambient air temperature, solar radiation, air velocity, and humidity are the parameters most significant to produce changes in bridge temperatures. As indicated for a typical section in

Fig. (1), ambient air temperature and solar radiation can be expected to follow two cycles, diurnal and yearly. The daily cycle produces temperature fluctuations and variations in the bridge structure. The yearly cycle is responsible for overall expansion and contraction bridge deck movements (Emanuel, 1978) . Further

Understanding of bridge behavior due to thermal effects is needed for design purposes. Most of the existing codes have no direct provisions, which guide the designer on how to calculate thermally induced stresses. Temperature stresses in a bridge structure due to non-uniform temperature distribution have attracted the attention of several investigators. It has been established in general that temperature induced stresses must be considered in the design of bridge superstructures (Rodolli, M., 1975).

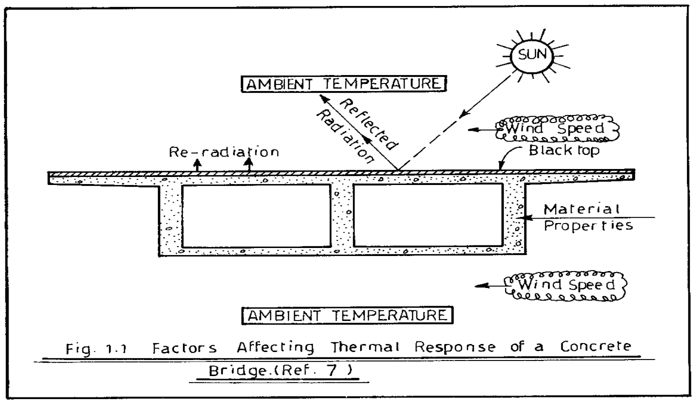

Fig. (1) Factors Affecting Thermal Response of a Concrete Bridge. (Priestly, M. J. ,1978)

Thermal Stresses (Johns, D. J. , 1965)

Most substances expand when their temperature is raised and contract when cooled, and for a wide range of temperatures this expansion or contraction is proportional to temperature changes. This proportionality is expressed by the coefficient of linear thermal expansion (α) which is defined as the change in length which a bar of unit length undergoes when its temperature is changed by 1°c. If free expansion or contraction of all the fibers of a body is permitted, no stress is caused by the change in temperature. However, when the temperature rise in a homogeneous body is not uniform, different elements of the body tend to expand by different amounts and the requirement that the body remains continuous in the same initial shape conflicts with the requirement that each element expands by an amount proportional to the local temperature rise. Thus the various elements exert upon each other a restraining action resulting in continuous unique displacements at every point. The system of strains produced by this restraining action cancels out all, or part of, the free thermal expansions at every point. This system of strains must be accompanied by a corresponding system of self-equilibrating stresses. These stresses are known as thermal stresses. Also, if the temperature change in a homogeneous body is uniform and external restraint limits the amount of expansion or contraction, the stresses produced in the body are termed thermal stresses.

THERMAL MOVEMENT

Thermal movement of a concrete bridge involves a displacement and a rotation caused by a combination of many factors such as:

The time-dependent solar radiation, air temperature, material properties (coefficient of thermal expansion, modulus of elasticity, shrinkage, creep), surface characteristics, section geometry, span length, types of bearing[4].The movement discussed in this research is the longitudinal movement (the longitudinal expansion and contraction movements). The magnitude of the range of movement experienced by a bridge during its life is one of the factors which influence the choice of both the type of expansion joints and the type of bearing to be used .(Emerson, M., 1981) Additional movements at joints can occur due to settlement, accidental structural damage, wind and vehicle impact. The magnitude of these movements is dependent on the severity condition. These movements are not considered in this paper.(Roland, L. P., 1983)

METHODS OF ANALYSIS

1- Priestly Method

A theory was presented by Priestly[7] enabling longitudinal temperature induced stresses to be predicted for an arbitrary section shape subjected to an arbitrary vertical temperature distribution. The following assumptions are made in developing the theory:

a- Material properties are independent of temperature.
b- Homogeneous isotropic behavior is assumed.
c- Plane sections remain plane after bending is valid.
d- Thermal stresses can be considered independently of stress or strain imposed by other loading conditions.
e- Temperature varies with depth, but it is constant at all points of equal elevation.

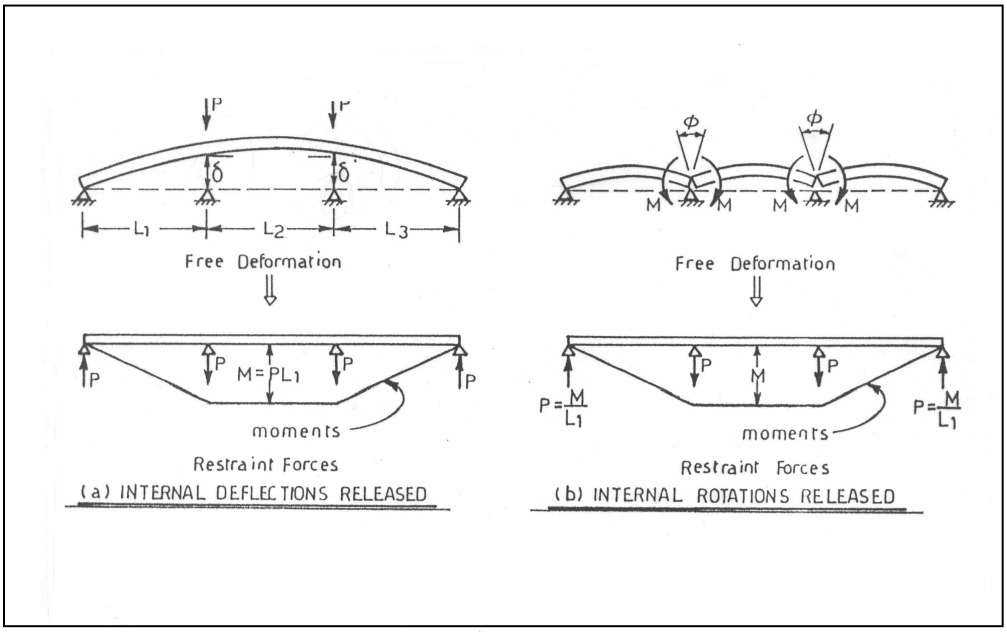

Fig.(2) Thermal Continuity Forces by Removal of Internal Redundancies. (Priestly, M. J. ,1978).

<u>The Concept of Equivalent Temperature Difference</u>

A procedure was developed by Abdul-Ahad[8] for calculating thermal stresses induced in continuous bridge structures by using the equivalent linear temperature distribution. The following steps are followed:

Step1-Compute the eigen stresses through the bridge cross section due to applied temperature distribution
Step2- Find the temperature required to produce eigen-stresses.
Step3- The temperature found in step 2 is subtracted from the applied Thermal load.
Step4-The temperature found in step3 is the linear temperature, which causes the deformation of the structure. The nonlinear part of the temperature which gives the eigen - stress does not cause any deformation because the resulting forces are self-equilibrating.

Step5- The linear temperature is applied as a load on the structure.
Through the use of this procedure, any shape of temperature distribution can be represented by an equivalent linear temperature distribution so that the linear temperature can be applied as a load on the structure using any readily available program by assuming a two – dimensional frame model to include the flexural stiffness of the piers.

The Finite Element Formulation

-A readily available computer program SAP86 was used. It is a finite element program for analyzing linear structural systems.
-The analysis was carried out by using 4-noded two-dimensional finite element.
-The Two-dimensional quadrilateral element which has been used in the mesh was plain stress elements. Each of the four nodes comprising the two-dimensional finite element has translational degrees of freedom in only Y and Z global coordinate directions.
- For the (2-dimensional) case plain stresses we have σ_y, σ_Z and τ_{yz} exist. The normal stress in x-direction is zero.
-For linear elastic isotropic material:
Ey=Ez=E
Vy=Vz=V
Gyz=G= $E/2(1+v)$
$\alpha y = \alpha z = \alpha$

-Thermal load: The program computes thermal load using the nodal temperature. The specified nodal temperatures describe the actual temperature distribution in the structure.

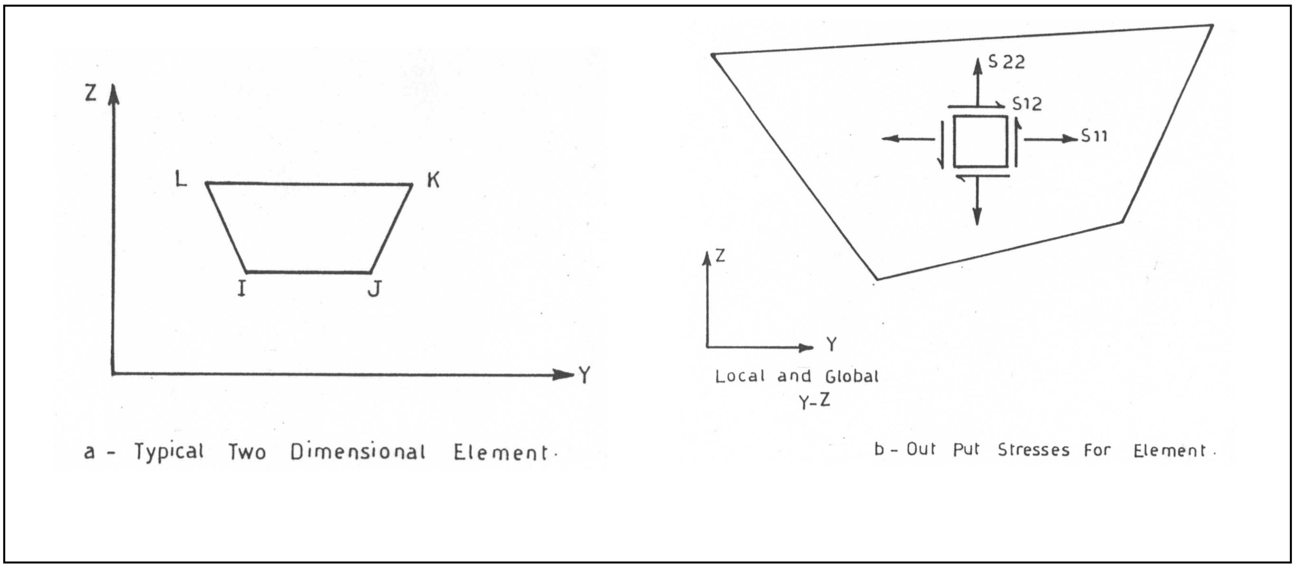

Fig.(3) Typical Element and Stress Output for Two Dimensional Finite Elements.

CASE STUDY

Tow types of prestressed concrete bridge have been investigated in this research. Thermal stresses and curvatures have been computed due to number of different temperature distributions.

1- Case A: Bab Al-Mouadam bridge (previously called 17 th July bridge).
2- Case B: Baghdad-Abughraib Bridge (A7).

In order to obtain an analytical solution, a model for the bridge is needed. Two analytical models are presented for each bridge:

Model No.1: A Simple Continuous Model.
Model No.2: Longitudinal Frame Model.

1-Case A: Bab Al-Mouadam bridge (previously called 17 th July bridge).:

After presenting the methods of the analysis, it is pertinent to apply the analysis to existing bridges.**Fig. (4)** shows the first model of the bridge the simple continuous one while **Fig. (5)** shows the second model of the bridge.

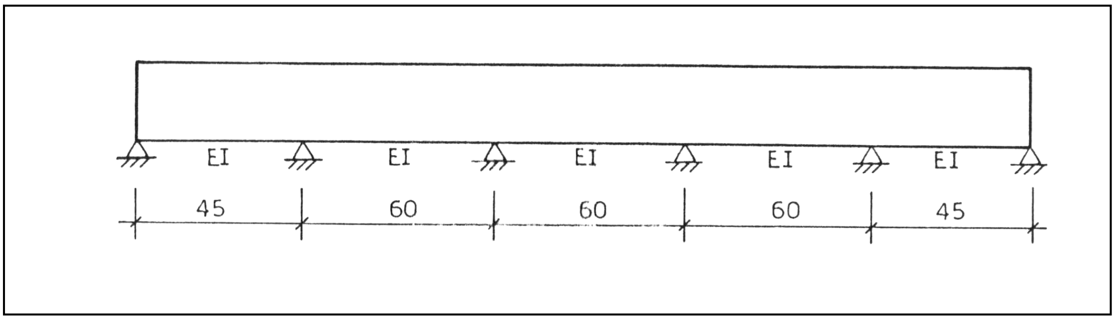

Fig. (4) Model No.1 of the Bridge Case A

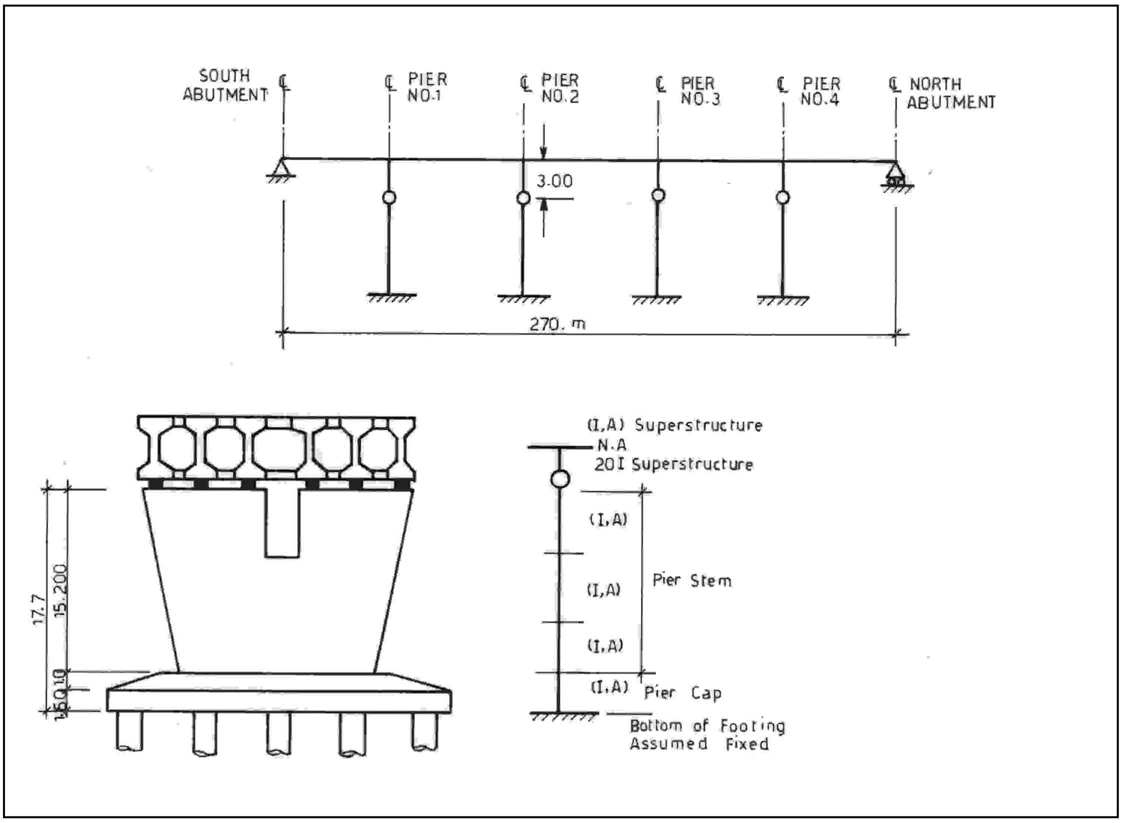

Fig. (5) Model No.2 of the Bridge Case A

Fig. (6) shows a typical comparison of curvature values due to different temperature gradients. The maximum value of curvature was obtained from ASSHTO Specification,($7.36*10^{-5}$ m^{-1}), while the value of curvature due to New Zealand and B.SSpecification are ($6.36*10^{-5}$ m^{-1}) and ($1.92*10^{-5}$ m^{-1}).

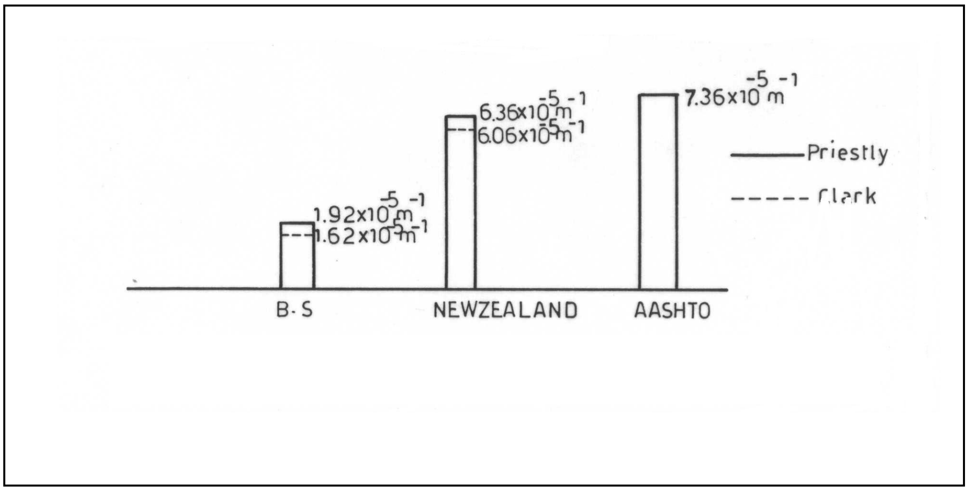

Fig. (6) Curvature Between Priestly and Clark Methods Due to Different Thermal Gradients for Bridge Case A.

Fig.(7) gives the maximum moment by AASHTO specification as (73.15 MN.m) by using Priestly method, while the values of moment by New Zealand and B.S. standards are (63.33MN.m) and (19.16 MN.m).

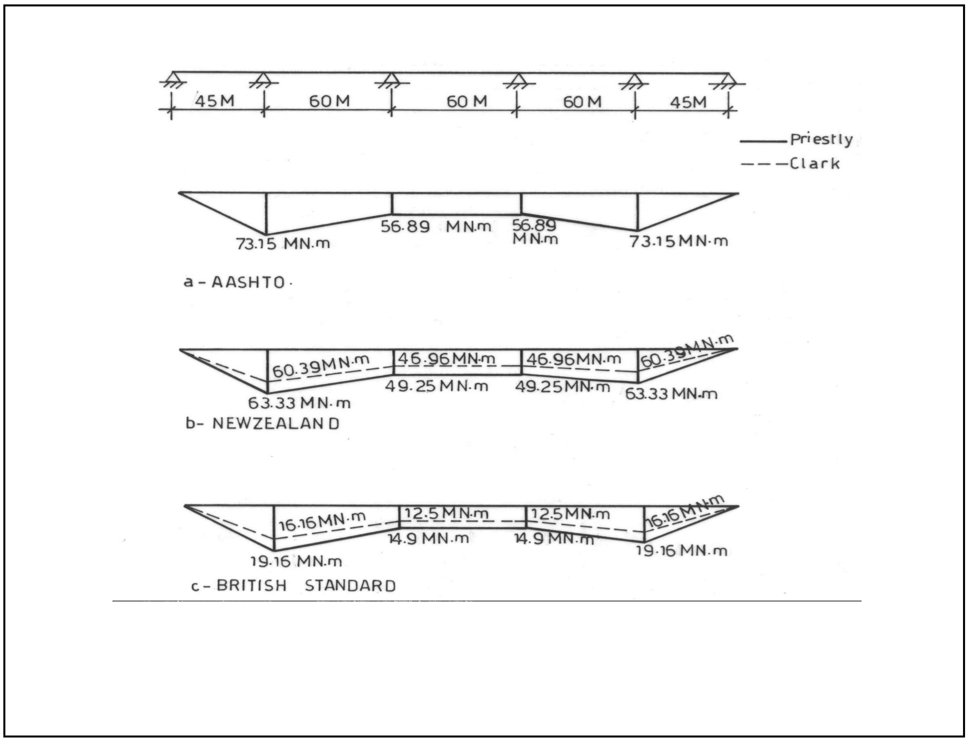

Fig. (7) Thermal Moment Comparison Between Priestly and Clark Methods Due to Different Thermal Gradients For Bridge Case A.

Fig. (8) indicates the sum of self -equilibrating and continuity stresses for different temperature distributions. Maximum value of compressive stress by New Zealand specification is about (2.2) times as large as those given by AASHTO and B.S. standards, while the maximum tensile stress by AASHTO is about (4) time as large as that obtained from B.S. standard and one time larger than that obtained from AASHTO specification.

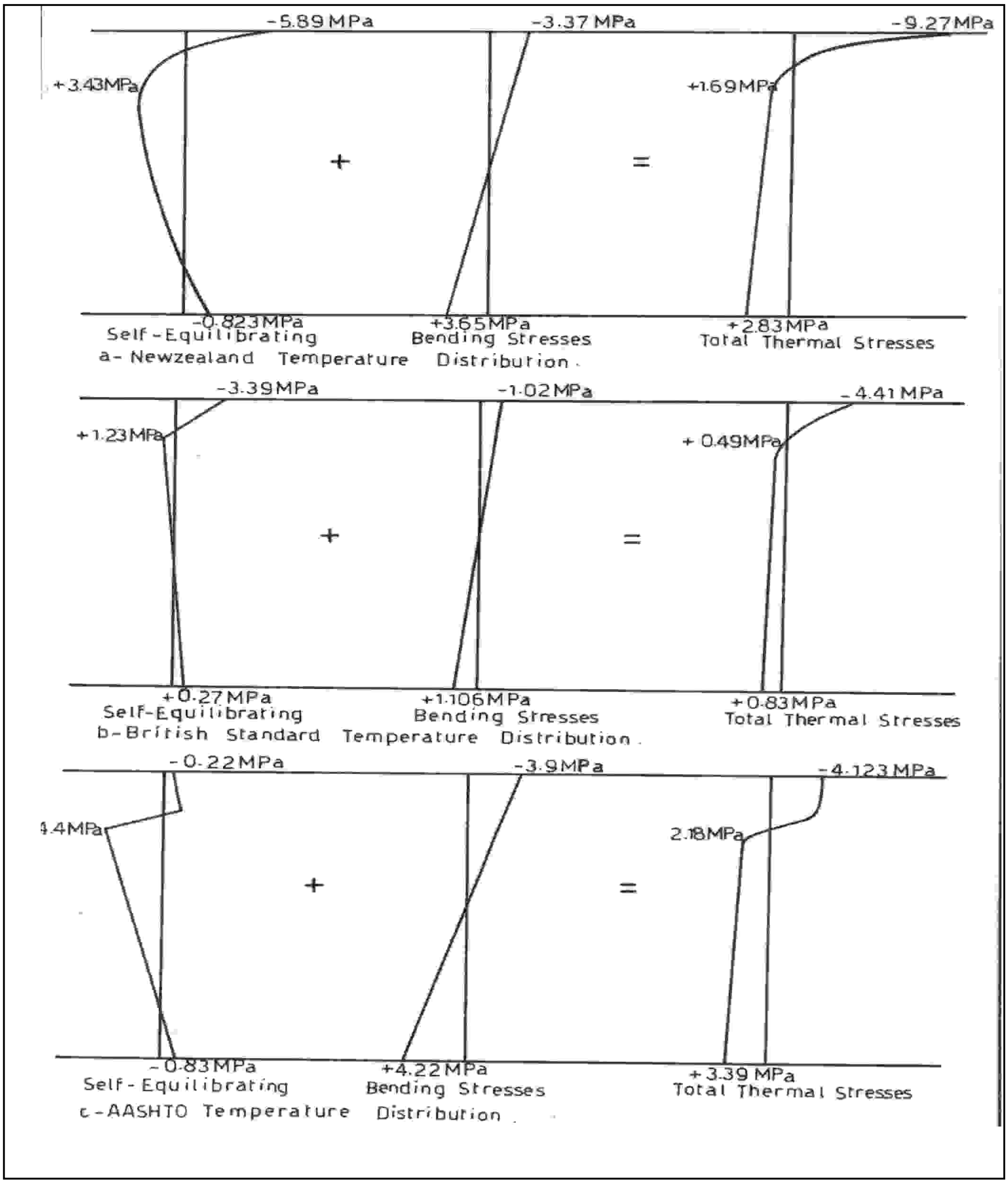

Fig. (8) Self-Equilibrating Continuity and Total Stresses Due to Different Temperature Distributions for Bridge Case A

Fig. (9) illustrates the equivalent linear temperature distribution for different temperature gradients. This temperature was applied as a load using model No.1. It is apparent that the bending moment and stresses computed by Priestly are about (81.3%) and (81.3%) of the moment and stresses computed by Abdu-Ahad using AASHTO specification.

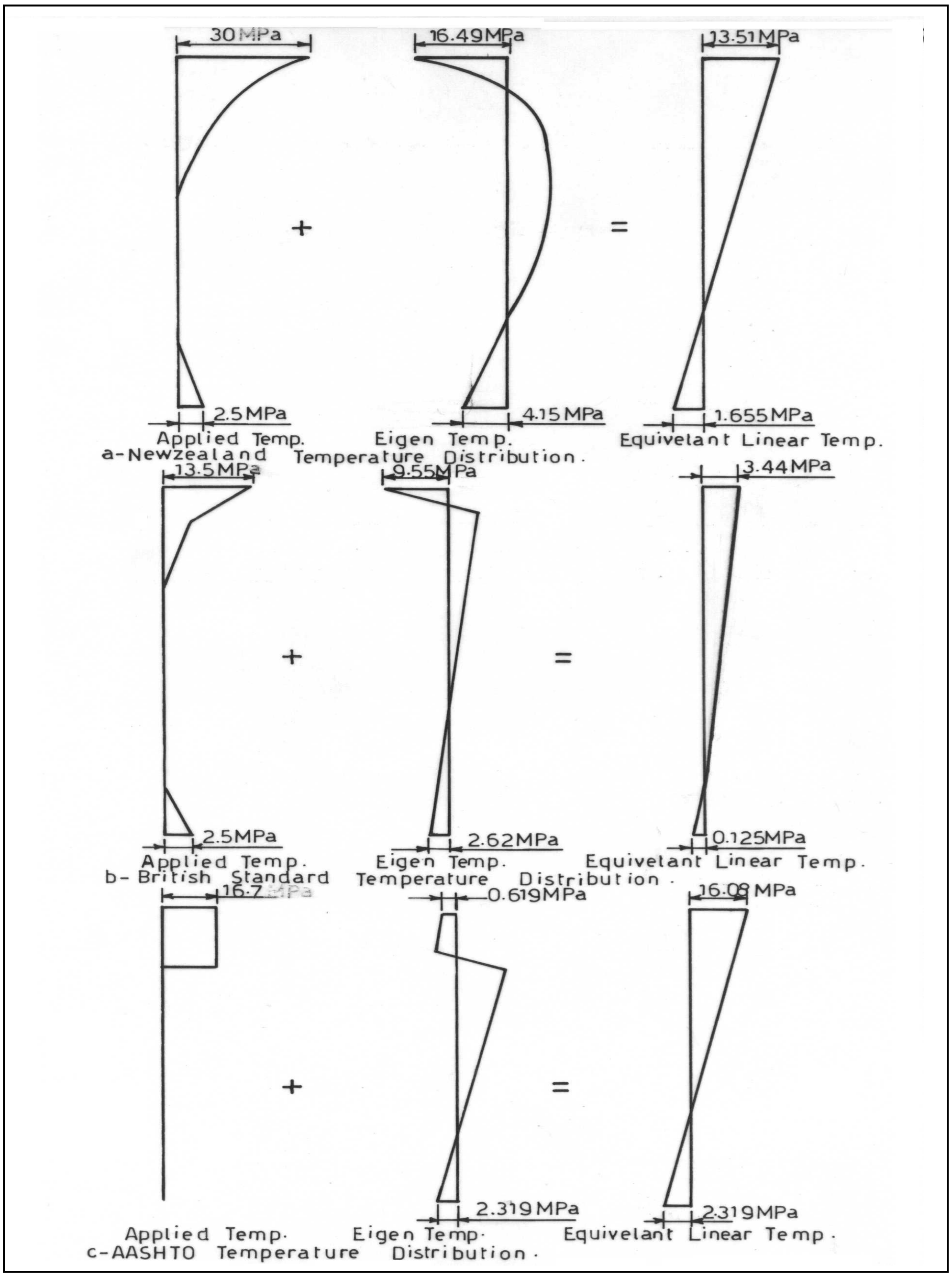

Fig. (9) the Equivalent Linear Temperature Distributions For Different Design Temperature Gradients For Bridge Case A.

Fig. (10) shows the longitudinal frame model for the bridge and using Abdul-Ahad method due to different temperature distributions. This model was used to predict the longitudinal movement at the abutment.

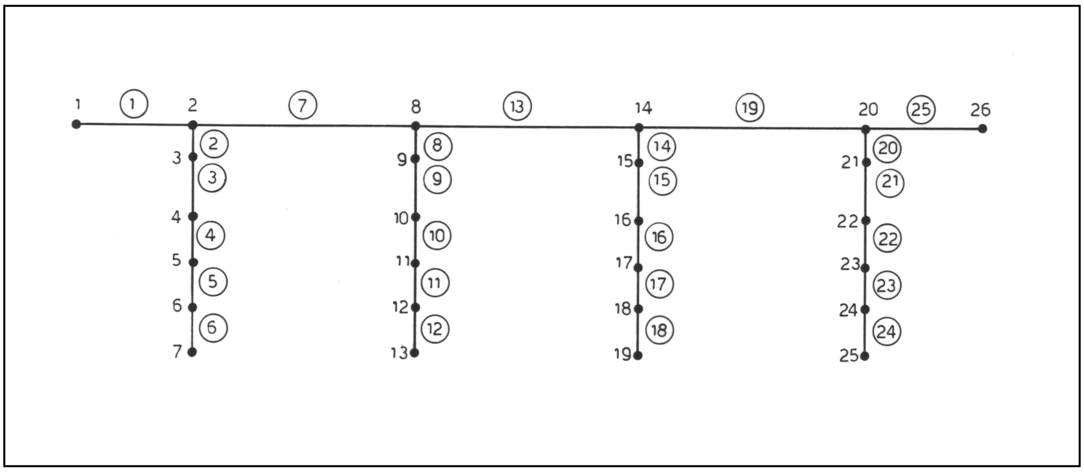

Fig.10) Beam Element of the Bridge Case A.

Fig (11) shows the mesh of the finite element for beam layout, the properties Listed in **Table (1.)** have been used as input data in the SAP Program.

Table1 Properties of Concrete

Property	Value
Modulus of Elasticity (Ec)	30×10^{3} MPa
Poissen's Ratio (υ)	0.2
Shear Modulus (Gs)	12500 MPa
Coeffecient of Thermal Expansion (α)	$12 \times 10^{-6}/C°$

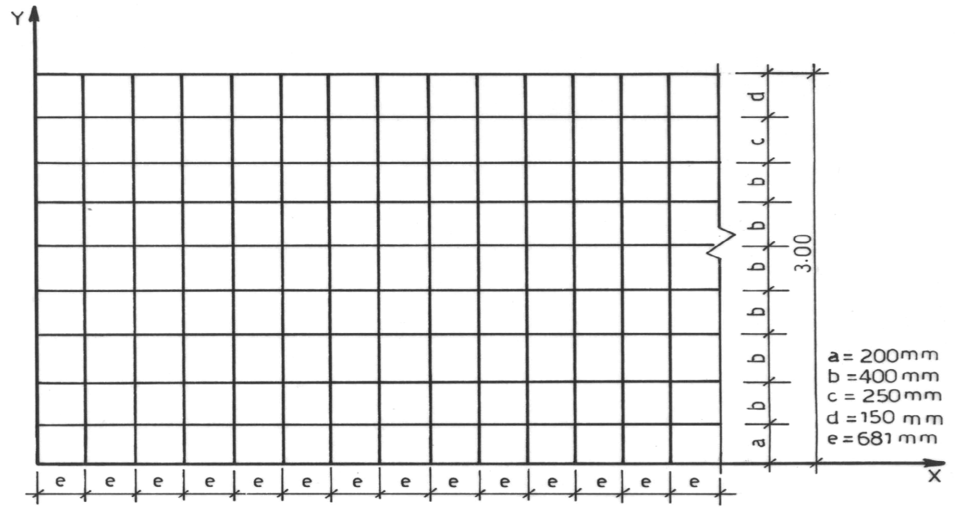

Fig. (11) The Mesh of The Finite Element Analysis For Beam of Bridge Case

Fig (12) shows a good agreement of stress values between Priestly and finite element methods using model **No.1** due to different temperature distributions.

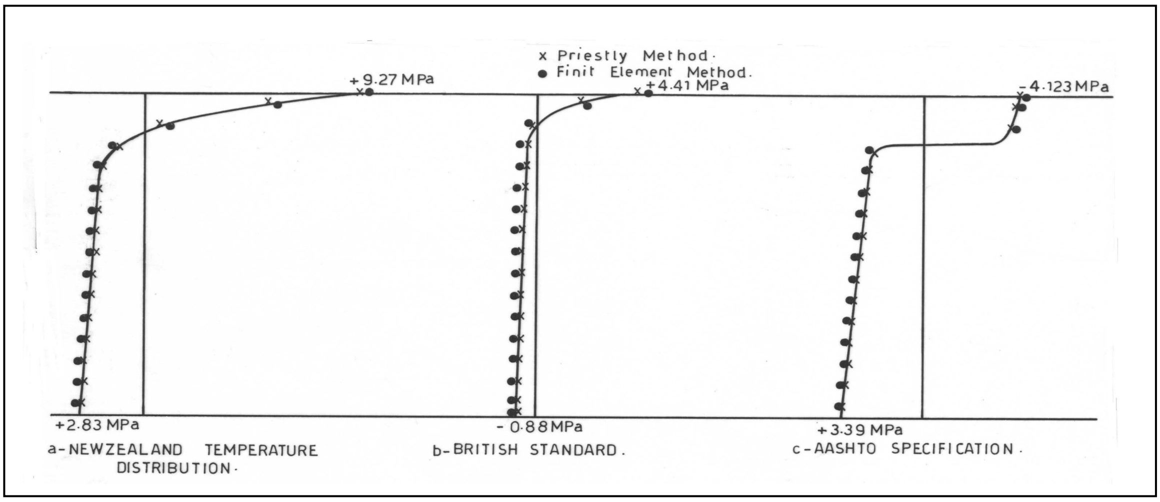

Fig.(12) Total Thermal Stresses Comparison Between Priestly And Finite Element Methods Due to Different Design Temperature Distributions For Bridge Case A.

Fig. (13) shows the stress distribution produced at the end of the first span by dead, live and thermal loads, due to New Zealand, British and AASHTO specifications. It appears that AASHTO specification overestimates the maximum tensile stress. While the maximum compressive stress induced by the New Zealand specification.

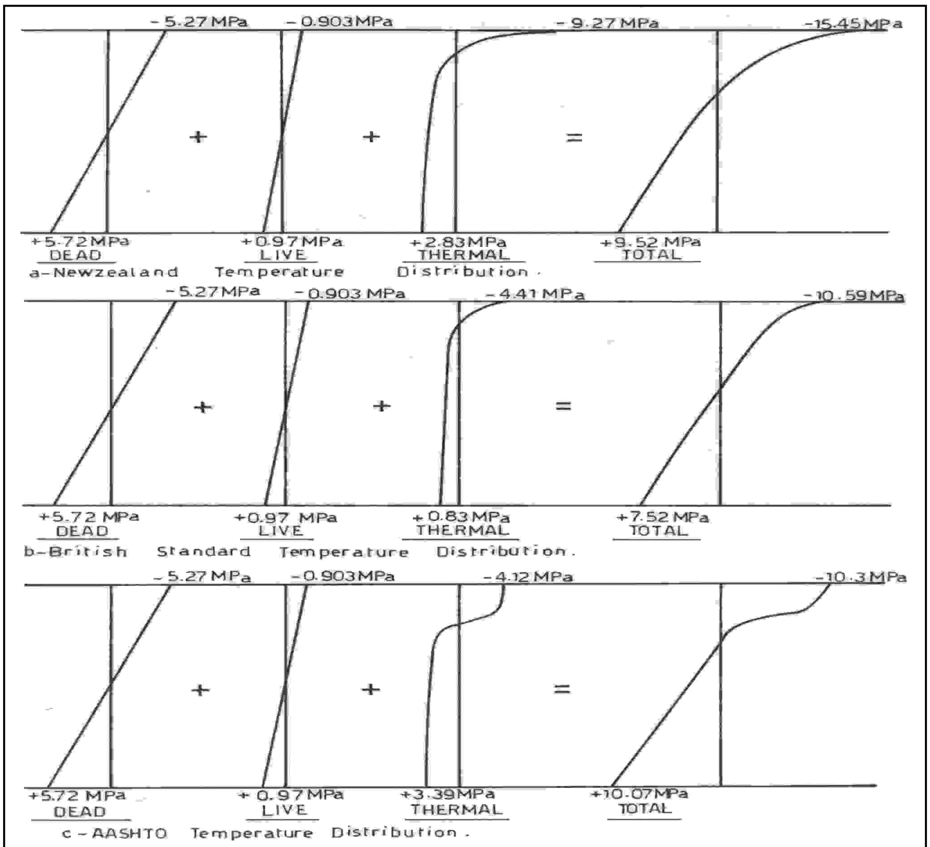

Fig.(13) Service Load Stresses Including Thermal Stresses Due to Different Temperature Distributions For Bridge Case A.

Case B: Baghdad-Abughraib Bridge (A7)

The same methods presented were used in the analysis of this bridge.**Fig. (14)** shows the first model of the bridge, the simple continuous one.

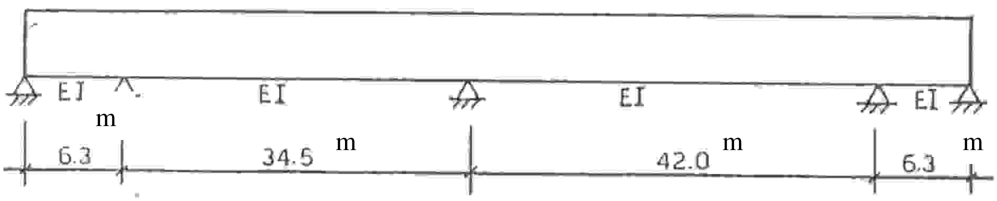

Fig.14 Model No.1 of the Bridge Case B.

Fig. (15) shows the second model of the bridge.

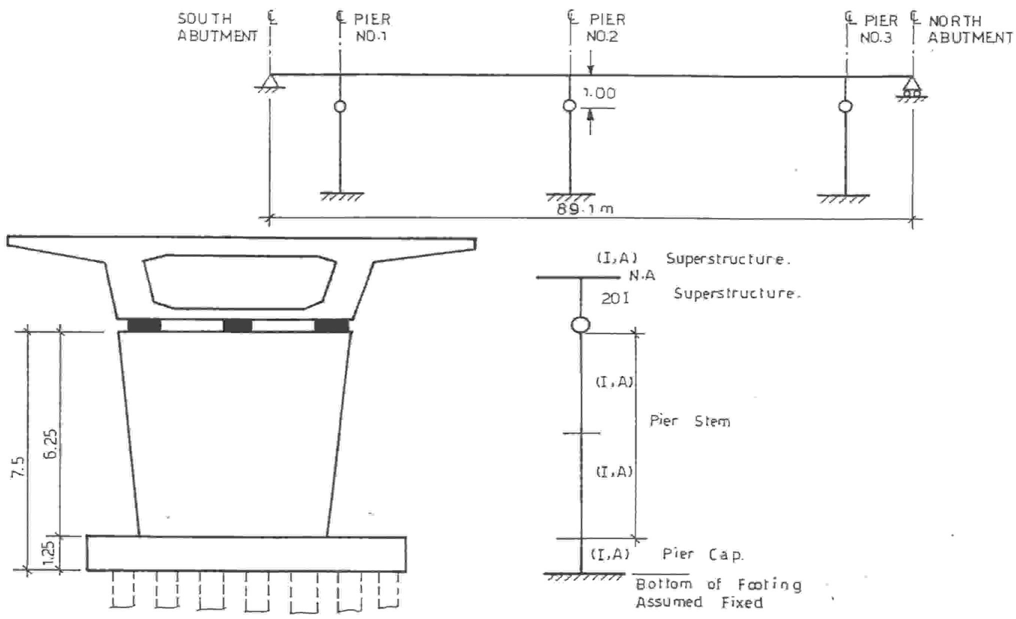

Fig .(15)Model NO.2 of the Bridge Case B.

Fig. (16) shows a typical comparison of curvature value due to different temperature gradients. A maximum value of curvature was obtained from AASHTO specification ($15.22*10^{-5}$ m^{-1}), while the value of curvature by New Zealand and B.S. specifications were ($12.96*10^{-5}$ m^{-1}) and ($3.96*10^{-5}$ m^{-1}).

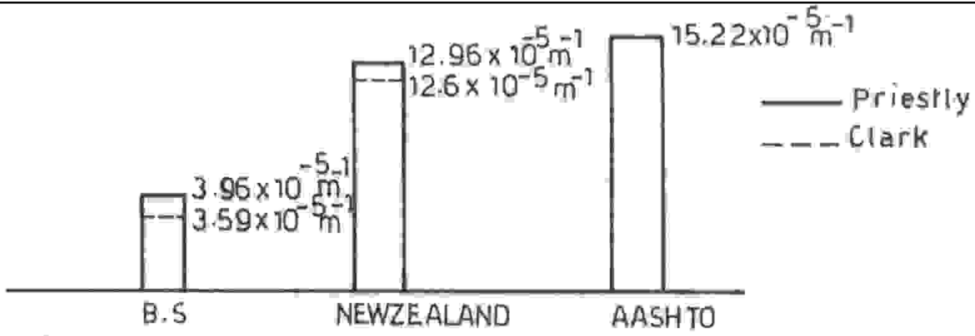

Fig.(16)Curvature Comparison Between Priestly and Clark Methods Due to Different Thermal Gradient for Bridge Case B

Fig. (17) indicates the maximum moment due to AASHTO (18.77MN.m) specification, using Priestly method, while the values of moment by New Zealand and B.S. were (15.99MN.m) and (4.88MN.m).

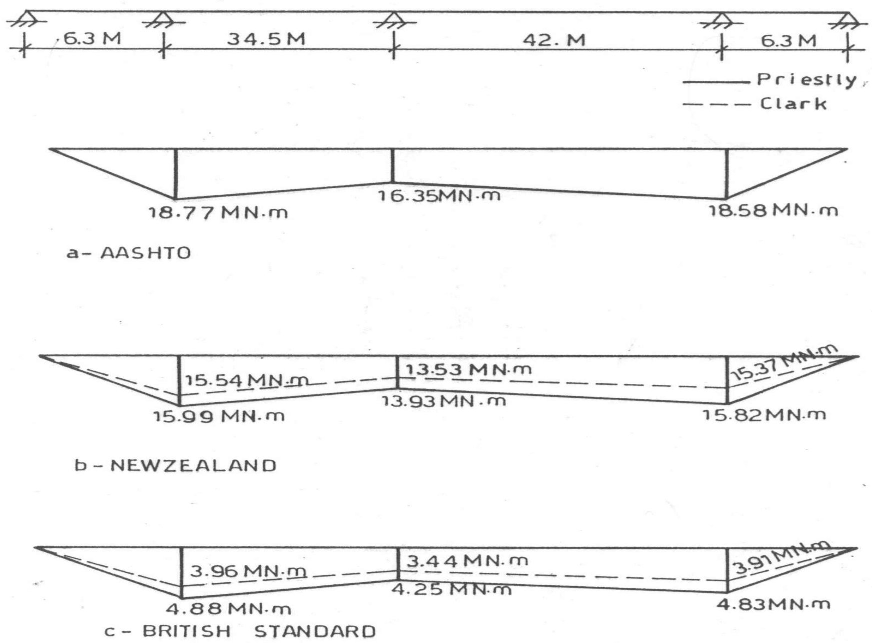

Fig.(17) Thermal Moment Comparison Between Priestly And Clark Methods Due to Different Thermal Gradients For Bridge Case A.

Fig. (18) indicates the sum of self-equilibrating and continuity stresses for different temperature distributions. The maximum value of compressive stress by New Zealand standard is about (2.0) times as large as those given by AASHTO and B.S.standards, and the maximum tensile stress by AASHTO is about (4.5) times as large as that obtained from B.S standard and (1.25) times larger than that obtained from AASHTO specification.

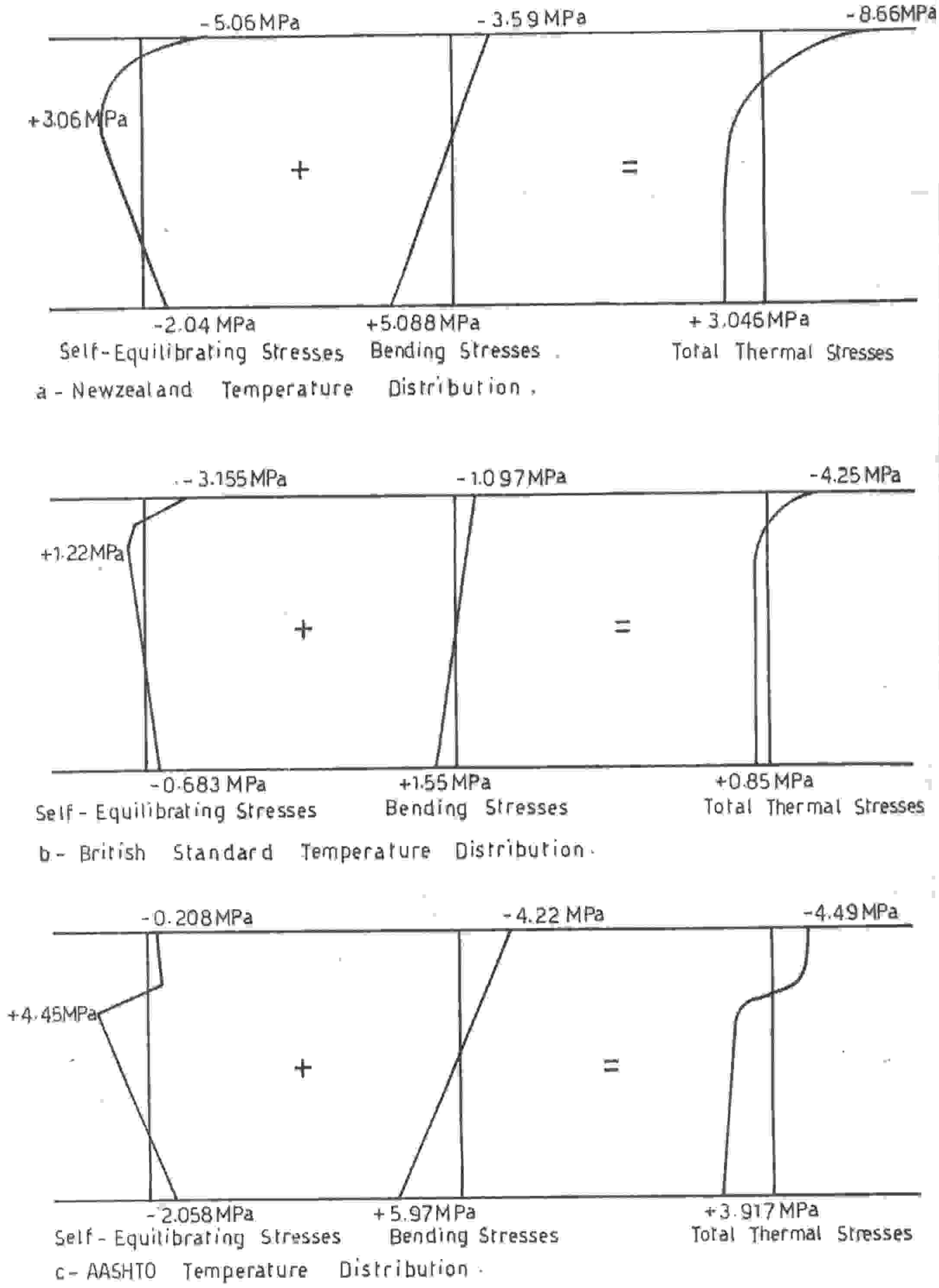

Fig.(18).Equilibrating, Continuity And Total Stresses Due to Different Temperature Distributions For Bridge Case B.

Fig. (19). illustrates the equivalent linear temperature distribution for different temperature gradients.

This temperature was applied as a load using model No.1, It is apparent that the bending moment and stresses computed by Priestly method are about (57.6%) and (57.6) of the moment and stresses computed by Abdul-Ahad using AASHTO specification.

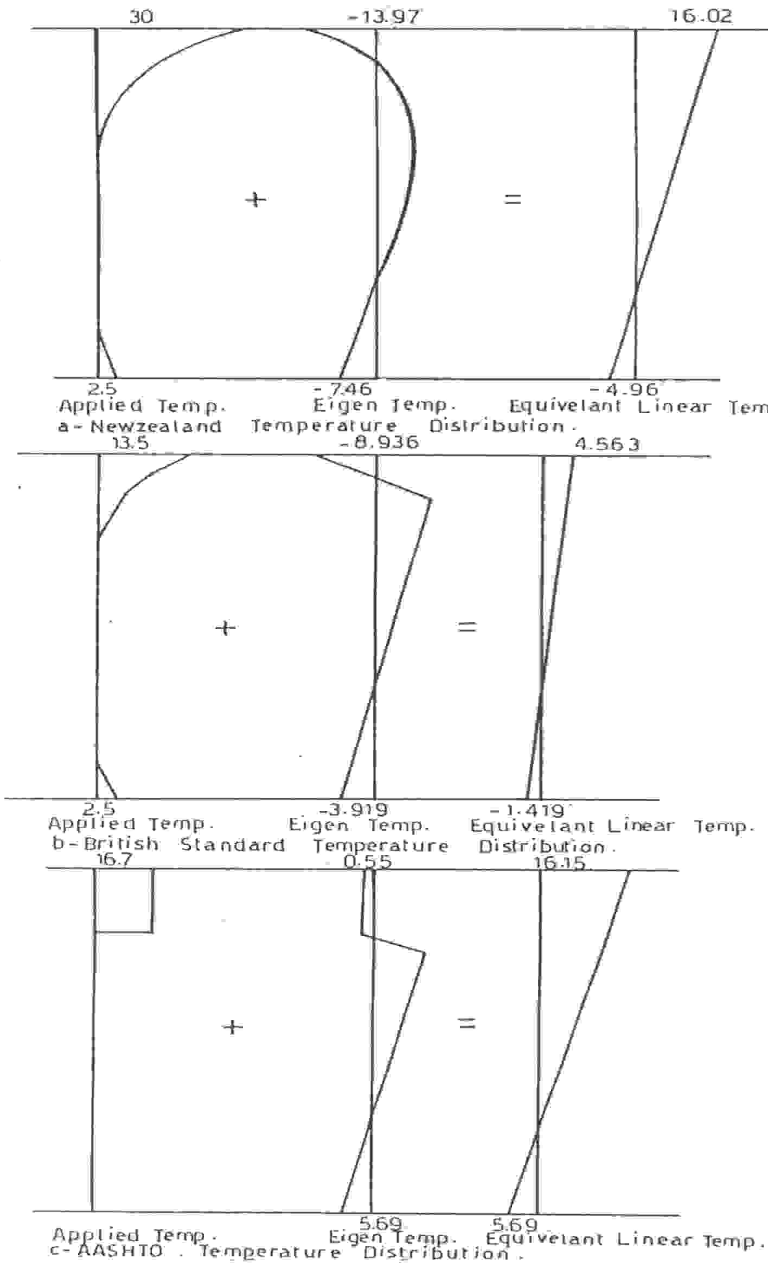

Fig. (19)The Equivalent Temperature Distribution For Different Design Temperature Gradients For Bridge Case B.

Fig. (20). shows the longitudinal frame model for the bridge using Abdul-Ahad method due to different temperature distributions, this model was used to predict the longitudinal movement at the abutment.

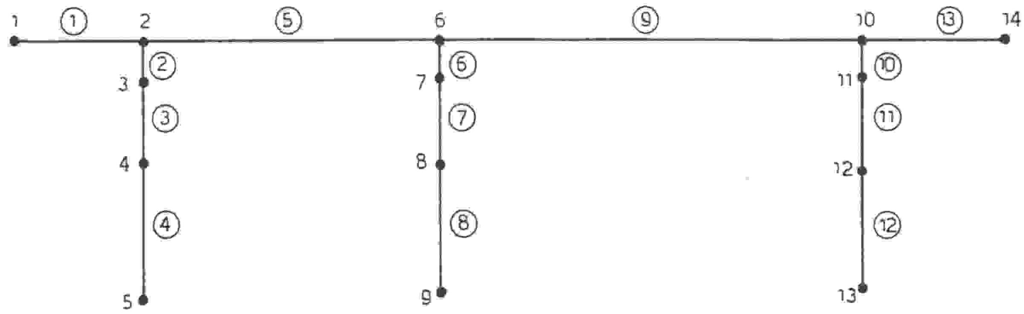

Fig.(20) Beam Element of The Bridge Case B.

Fig. (21) shows the mesh of the finite element for beam layout, the same properties listed in **Table 1** were used.

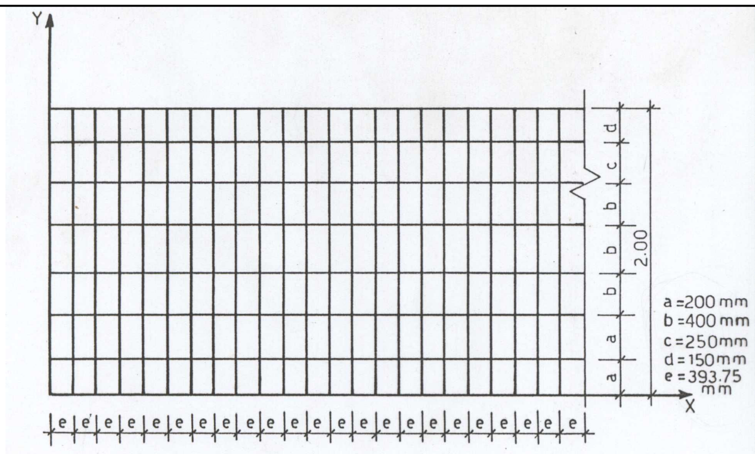

Fig. (21) the Mesh of the Finite Element Analysis for Beam of Bridge Case B.

Fig. (22) shows a good agreement of stress values between Priestly method and the finite element method using model No.1 due to different temperature distributions.

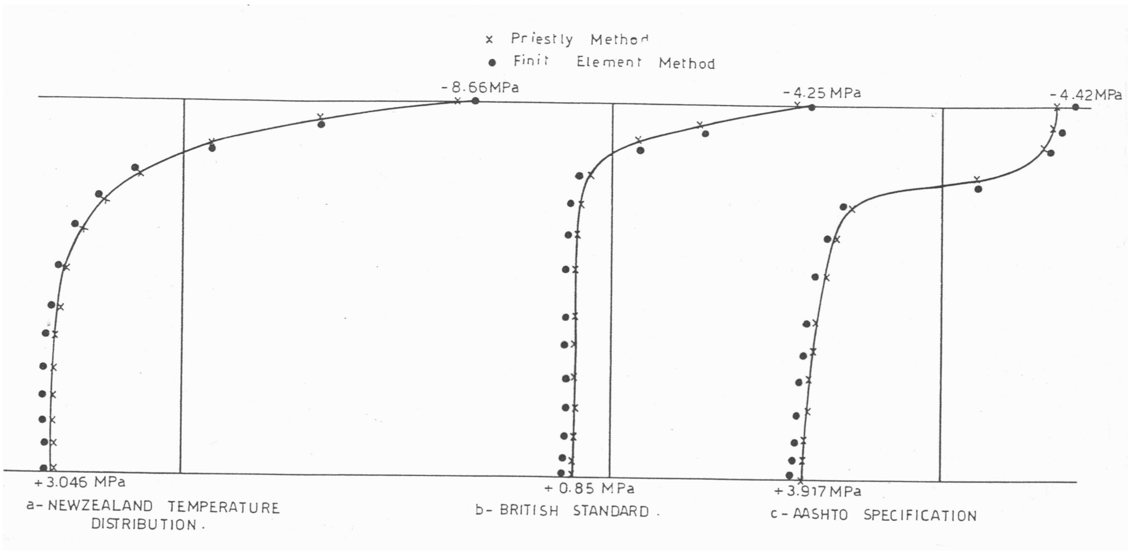

Fig. (22) Total Thermal Stresses Comparison Between Priestly And Finite Element Method Due to Different Temperature Distributions For Bridge Case B.

Fig. (23). shows the stress distribution produced at the end of the first span by dead, live and thermal loads, by New Zealand, British, AASHTO specifications. It appears that AASHTO specification overestimates the maximum tensile stress, while the maximum compressive stress induced by the New Zealand specification.

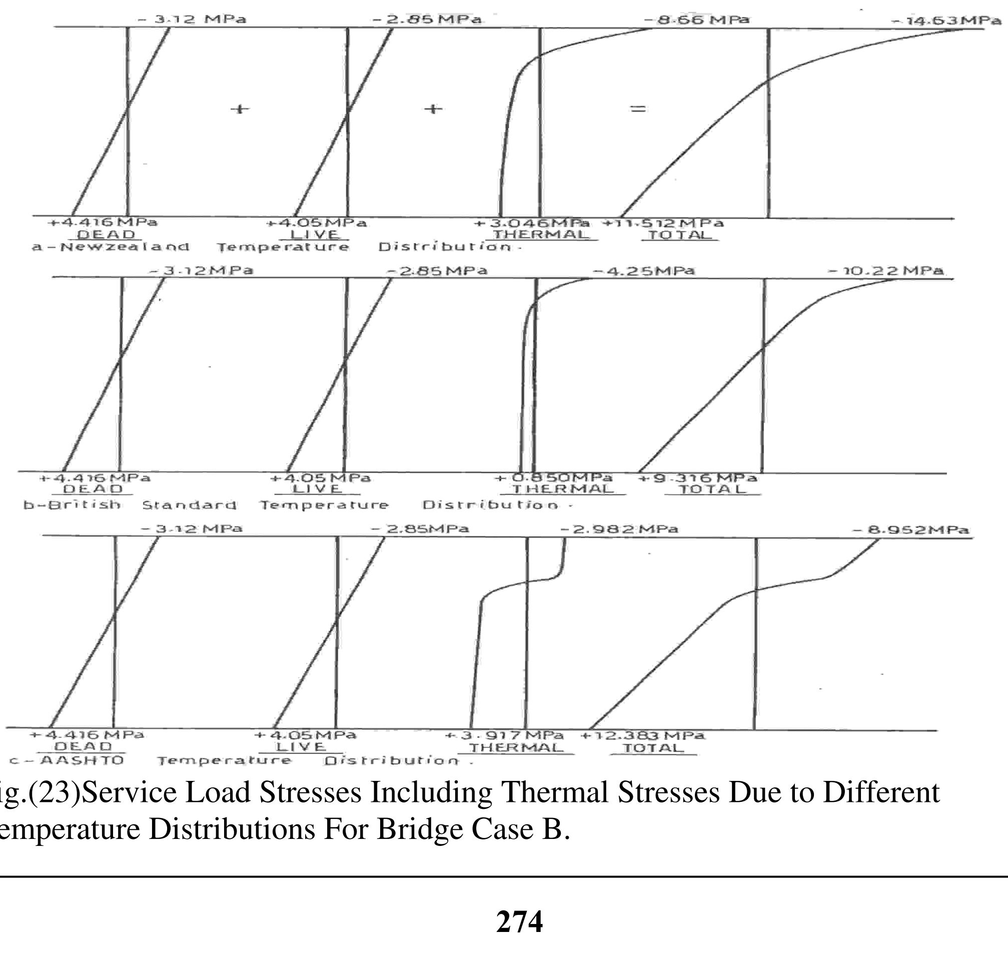

Fig.(23)Service Load Stresses Including Thermal Stresses Due to Different Temperature Distributions For Bridge Case B.

However, it can be concluded that thermal effects must be considered when assessing the serviceability of the bridge under design conditions.

CONCLUSIONS

- Results showed that the magnitudes of the longitudinal and continuity stresses depend on both the magnitude and the temperature distribution through the cross section of the bridge.
- The bridge geometry will influence the longitudinal movements that occur as a result of temperature change. Analysis of two selected bridges with various lengths indicates that the longer bridge exhibits larger movement.
- For the two cases studied, comparison between the three codes indicate that there is a convergence between the New Zealand and AASHTO specifications in calculating the curvature and the moment while the British standard underestimates these values.
- For higher temperature with B.S (5400), the agreement with the other two codes becomes better in calculating curvatures and moments.
- The analytical models developed for the bridge which greatly simplify the complexity and dimension of the problem, can be used to predict thermal stresses, due to any shape of temperature distribution.

REFRENCE

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