



An Analysis of Plates and Shells Structures in Modern Engineering

Hussam Ali Mohammed, Zeena H. Hussain

Building and Construction Engineering Department, Al-Mussaib Technical Collage, Al-Furat Al-Awsat Technical University, Iraq.

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ABSTRACT

The plates and shells were deeply interpreted and analyzed for homogeneous, functionally graded, or composite body laminated plates and shells acting under different load effects, bending, and shear loads. Recently, some models of specified layered shells were generated by continuously fitting and linking material properties in the corresponding layers. Some specified layered or honeycomb shells can be replaced by analogous plates and shells subjected to normal or bending loads. The mentioned topics are relevant in the present research due to their use in aerospace, civil, marine, biological, and other types of engineering that require reliability, safety, and resistance during their lifetime. The known results highlight different methodological, numerical, and technical arrangements between solutions and requirements. This inspires the introduction of a unifying study and presentation with the main distinction in the problem type. In addition, an anisotropic or heterogeneous power-law elasticity or power-law strength for different shell structures can be constructed by using variations of sub-cases or sub-constraints formulation. Finally, in this paper the plate and shell are presented as structural member in modern engineering subjects, such as domes of mosques.

1. Introduction

Plates and shells are essential components of many structures, including cars, planes, and buildings. These components are low in weight and high strength, also, an essential part of modern engineering applications. In typical the applied of algebra courses for plates and shells are complicated structures that do not fit readily into the various categories of problems that typically comprise a course. A plate is, while not infinite, in part much longer when compared to its other two dimensions. It is thin when compared to its other two dimensions, often many times thinner compared to its length and width. Plate analysis

typically breaks plates into three major categories, based on their contour, which may be rectangular, triangular, or polygonal. [1][2]

Because of the external dimensions of plates are typically much greater than the internal dimensions compared to the smallest of the plate's cross-sectional dimensions, the bending conditions on the outwardly spanning surfaces of the plate dominate the behavior of the plate. As a result, the plate is capable only of taking bending loads. Unlike the beam, which can take most loads, the plate has ability to resist only a small number

Corresponding author:

E-mail addresses: com.hus@atu.edu.iq (Hussam), zeenaalkhafajy1@gmail.com (Zeena)

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of stress states when it is subjected to forces. When under the dual action of transverse force and axial compression, the flat plate will experience biaxial bending; when under the combined action of transverse force and axial force, the flat plate will experience transverse and axial displacement. Unlike the beam applied to any of the faces or the surface of the plate, a load distribution is applied that can produce a system of neglected surfaces resultant. [3]

1.1. Definition and Classification of Plates and Shells

Plates and shells are common structural elements that are widely used in modern engineering structures. Both plates and shells are planar constructions, with the first pulled by bending and the second by bending and membrane stresses working simultaneously. The difference is that the characteristic dimensions of the shells change along the normal to the middle surface, whereas for plates, the dimensions are constant. In this paper, the elasticity theory laws are used for modeling the state of warping of the plate, which is a priori working by in-plane forces and moments that do not belong to the theory of thin-walled constructions. [4]

Both of these elements are conditionally divided into two more and less flat, which completely violates the mathematical basis of the theory of elastic stability, but buckling problem is still from being solved, whether experimentally or by means of numerical finite element analysis. In practice, engineers tend to consider thin plates and orthotropic thin-walled constructions. However, this creates some inconsistency, while in the theory of elastic stability, there are no critical problems. The laws of the theory of elasticity are used for modeling the state of warping of the plate, which is a priori working by in-plane forces and moments that do not exceed the strength of the material according to thin-walled constructions. [5]

1.2. Importance in Modern Engineering

In modern engineering, shell and plate structures has highly considered in most applications, such as pressure vessels, aircraft, space shuttle tanks, buildings with circular and spherical geometries,

industrial boilers, steam turbine blades, submarine pressure hulls, and offshore platforms. Many other structures, such as cooling towers, paper mill drying cylinders, automotive bodies, chemical reactors, missile shells, buildings with square and rectangular geometries, machine components, architectural vaults, and bolted plates, are designed by combining the concepts of plate and shell behavior. These structures are not only complex in geometry but also involve large deformations while in service. Shell structures are also found in artificial applications, such as large boiling vessels for commercial purposes, missiles skinned with thin materials, or metal containers rolled to form circular geometries, as well as small apartment buildings and large exhibition domes used instead of concrete slabs. [6]

2. Historical Development of Plate and Shell Structures

To approach the complexity of the behavior of structural elements, structural engineers often use a two- or three-dimensional idealization of the structure. When the structure contains a surface that is relatively shallow compared to its other dimensions, this surface element can be defined in general as a shell and, in the limiting case of its being very thin, as a plate. Since it is often defined by two parameters, these structures present a particular challenge in structural theory. Consequently, many developments in applied mathematics have been motivated by problems arising in plate and shell structural behavior. These surfaces frequently occur in practice, and engineers are continually responding to problems associated with large deflections of surfaces that are usually part of larger three-dimensional structural systems. The plate and shell behavior is presented to give perspective on the new developments that will impact modern structures. [7]

Theoretical developments for elastic plates and shells have been made during the four or five centuries since the formulation of the early model for shallow curved plates and the membrane analogy for flat as well as for curved plates. Subjected to certain types of applied loads, the initially single-piece forms of these surfaces may deflect in interesting and apparently unstable ways. The analysis of such unusual paths of

equilibrium for plates and shells has given much impetus to the development of applied mathematics in the last century; in particular, much of the science of applied mathematics introduced to understand direct and inverse problems of the calculus of variations concerns problems in this area. Researchers in applied mathematics who studied such intense deflections led to the development of geometric singularities and catastrophe theory formalizations. [8]

3. Basic Concepts in Structural Mechanics

The learning of the theory of elasticity is, in general, a requisite. Some basic concepts in this context are discussed, essentially giving a brief review of the concepts of stress, strain, displacement fields, equilibrium, and compatibility of deformations. Some concepts in linear elastostatics and the stress-strain relations valid for isotropic solid are presented. A few remarks are given on the principles in elasticity, and a focus is made on variational methods. When used in conjunction with the admissible fields of wave propagation, provide relations similar to the principle associated with rays. The body may deform, provided that the conditions of equilibrium and compatibility are observed. The conditions of equilibrium are derived from the laws of gravity and Newton. The field should also obey the conditions of compatibility, which are derived from the laws in the domain. If the body consists of several points, each of them may deform or, in other words, the particle behavior is affected by the history of the loading. Therefore, structural members should be studied regarding strength because their ability to carry the external non regular loads adequately is directly associated with the high performance of the section throughout time. When the body moves, the forces and the moments acting on are related to the variations of the displacement value. These values can be determined by the equations of equilibrium, directly derived from the principles of Newton. [9]

3.1. Equilibrium and Compatibility

The structural basis for the analysis of any engineering problem is the principle of the compatibility of deformations (COD), which states that the displacement value must be such that the

deformed body continues to remain in contact throughout the load-carrying process. One component of COD is the principle of the conservation of differential topological properties during a deformation, which is the visual and intuitive requirement that any two intersecting lines remain along the axes of intersecting surfaces. the principle leads to a kinematically non-admissible deformation that lead to fail. The algorithms to evaluate simple problems are outlined to illustrate the ease with which problems are solved using a general-purpose computational program that uses the simple and rational sub-parametric assumptions developed by adapting the concepts and results presented, an assemblage of h-finite elements is developed that is capable of evaluating the response of plates [10][11].

The assemblage is based on the well-known Reissner-Mindlin model, using polynomial functions to approximate the displacement value in each adapted element; analytical integration is used throughout the problem. The elements are used to evaluate the response of test problems since the model has the same mathematical characteristics as the finite element method and employed to verify the analysis by comparing the results with exact ones and give insight into the assumptions and mechanics of h-continuum plate models. The accuracy of the plate elements is enhanced using assumptions developed, experimented on, and validated. The advantage of this assemblage is its rational development and functional simplicity due to the few assumptions used. Studied show that the element can be joined to develop various assemblages. [12][13]

3.2. Constitutive Equations

When assuming small strains and small rotations values with no permanent deformations, the material can be assumed to be linearly elastic. This implies a relationship between stress and strain, for which both can be expressed as functions of only six parameters: two elastic module, three Poisson's ratios, and the angle of the anisotropic plane. The basic relation can be expressed as follows: [14][15][16][17]

$\sigma = C \epsilon$ where the stress vector in the anisotropic coordinate system is given by:

$\sigma_1 \sigma_2 \sigma_3$. C is the elastic matrix of the material, and the strain vector in the anisotropic coordinate system is given by:

$\epsilon_1 \epsilon_2$ and ϵ_3 .

For a plate element, it can be shown that the principal material properties can be given as a more simplified matrix, the constitutive matrix. The principal properties of an orthotropic plate can be given by the use of the principal coordinate system for which:

$\sigma = Q \epsilon$ where the stress vector in the anisotropic coordinate system is given by:

$\sigma_x \sigma_y \tau_{xy}$. The strain vector in the principal coordinate system is given by:

$\epsilon_x \epsilon_y \gamma_{xy}$. Based on this, the constitutive equations for a general orthotropic material can be expressed as: $Q = \begin{bmatrix} E_{11} & 0 & 0 \\ 0 & E_{22} & 0 \\ 0 & 0 & G_{12} \end{bmatrix}$ $\begin{bmatrix} 1 - \nu_{12}\nu_{21} & \nu_{12} & 0 \\ \nu_{21} & 1 - \nu_{12}\nu_{21} & 0 \\ 0 & 0 & 1 - \nu_{12}\nu_{21} \end{bmatrix}$. Here, E_{11} and E_{22} are the moduli of elasticity in the 1 and 2 directions, respectively. ν_{12} and ν_{21} represent the Poisson's ratios, and G_{12} is the shear modulus of elasticity.

4. Theories of Plates and Shells

Plates and shells are widely used in modern engineering and have been studied not only through general theories of anisotropic elasticity but mostly through special theories and solution methods. These theories and methods have proven to be quite economical, but there have always been questions about the qualifications of the assumptions such as the Kirchhoff plate theory, Dirichlet shell theory, Love's shell theory, etc. some representative results of mathematical theories and solution methods for the two-dimensional plates, three-dimensional plates, bending theories, and conical plates are formulated and discussed.

The theories of plates and shells are theories of thin-walled structures which are composed of lamina. The basic hypotheses on plates are (1) geodesic lines in the middle surface of a plate before deformation remain curved after deformation, (2) the middle surface of the plate is normal to the fiber direction before deformation

and remains straight after deformation. These hypotheses lead to the Kirchhoff plate theory—that is, the displacement at the middle surface (plate) is composed of two components and is normal to the fiber direction. Thus, there are only five equations in the stress form of Kirchhoff plate theory. Although there are plane stress, plane strain, and three-dimensional theories in mechanics, no higher order theories, such as sectorial or corner theories, have been proposed yet. [18][19]

4.1. Classical Plate Theory

This theory develops the structural theory of thin plates, which has become one of the fundamentals of modern engineering in the improvement of shell theory. In depth, in almost any practical structure, this basic unit of modern analysis is of secondary importance. The study presented three kinds of two-dimensional structural theories represented a bridge, from plates to shells and then to three-dimensional structural theory. The three two-dimensional theories are: 1) assumed stress values for bending deformation of plates, 2) an analysis in terms of the same classical solution for slab deflections, and 3) a vertical shear column analogy. The results compared to clarify the differences in their predictive capability.

Classical Plate Theory: The development begins with an analysis of the physical conditions for bending behavior so that to recognize many of the results obtained from the theory, namely, that there are no transverse shearing effects and that no in-plane behavior is associated with the plate deformation, only to the lowest order. a portion of the structure is a plate or so thin in another parameter that its apparent behavior is two-dimensional. For development purposes, need to consider a square plate on which the lower plate surface edge of parallel plates of identical material properties. [20]

4.2. First-order Shear Deformation Theory

The Kirchhoff plate theory neglects transverse shear deformation effects and presents excellent results for thick plates under symmetric loads. However, for thin plates simply supported under non-uniform stresses, the shear lag effect plays an important role and must not be neglected. The

transverse theory, in which the transverse shear stresses are calculated correctly and the transverse shear strain remains constant, disagrees with the constrained nature of the plate and physically it is incorrect. For this reason, the transverse shear deformation energy is not taken into account in the classical plate theories based on the first-order transverse theory. This aspect is only satisfactorily achieved in third-order theory, where the shear and normal stress distribution assumed in the transverse directions makes it possible to describe the plate dependence on its thickness. The present closed-form solutions extensively validate the consistent asymptotic behavior of third-order shear deformation plate theory. The individual behavior of thin-walled cylindrical shells under various types of loading is analyzed by using classical thin shell theory. When analyzing plates and shells, bending approximations are used, which mostly ignore the transverse shear deformation and present excellent results for the treatment of many two-dimensional problems. However, this treatment leads to important limitations that must be taken into account for some specific problems. Assuming that the plate or shell is made of an isotropic material, a large number of plate and shell theories are available, assuming different and developed transverse distributions for the deformations of these structures. In the most classical ideas, with treatments that normally neglect the transverse shear deformations of the plate, The Reissner studied was the first to involve the plate or shear wall with the transverse shear deformation. This development was essential and considered a considerable improvement over classic plate theories. [21]

5. Finite Element Analysis of Plates and Shells

The derivation of the energy process of finite elements is carried out and based on this derivation, the finite element systems and associated stress matrices are constructed for plate and shell structures with arbitrary geometry. The governing differential equations of plate bending and shell are established by the principle physical effect and relations. Based on the finite element formulation and governing equations of plates and shells, the displacement finite element analysis software for plate and shell deformation was developed. Panels with arbitrary shapes can

be defined by the finite element system. Analysis and applications are demonstrated with several examples. Additionally, many examples were analyzed or reanalyzed, further demonstrating the capabilities. [22][23][24]

The numerical procedure for the finite element analyses, and the computer solution process for circular and arbitrarily shaped panels and patch-stiffened panels are conducted. The numerical results and limitations are highlighted. An application of the developed finite element results to the investigation of the collapse performance of metallic panels under immersive blast loading is implemented. For the large deflection problem, the function of essential nonlinear elements for each element is established. After the analysis and solution of the linear system, the deflection of structures at the equilibrium state is determined. The deflection simplification technique of the large deflection problem considering the quasistatic behavior of plating structures is employed and discussed. The large deflection behavior, such as the post-buckling paths and limit loads of plating structures, is analyzed. [25]

5.1. Modeling Considerations

This parte is divided into two main sections. In the first part, the anisotropic material static and free vibration behavior of orthotropic plates with openings is considered using the Boundary Element Method. In the second part, the perforated material axisymmetric thin shell behavior under axial-symmetrical and asymmetric loadings is considered using two different direct methods based on displacement fields. the behavior of plates and shells is studied from a purely structural standpoint, allowing for the mechanical strength and stiffness (as well as results interpretation) of these structures to be understood. [26][27]

There are several ways to model the behavior of a plate or a shell. From a purely structural standpoint, all methods producing an equivalent elastic model should converge to the same results and most of the usual plate and shell modeling issues are considered. By depending on classical plate and shell theory how to build basic equilibrium equations. Except when explicitly stated, the actions of these models are applied to a

plate or a shell with the main material being an orthotropic material. After reminders of classical linear plate theory equations, so that the orthotropic thin laminated plates composed of three layers. As in classical Timoshenko-Mindlin theory, suppose the middle layer, denoted by 1, is the plate plane. This middle layer is thus free of thermal, mechanical, or structural stresses. [28][29]

5.2. Meshing Techniques

In general, for plates and shells, the determination of accurate stresses or displacements entails the construction of reinforced concrete models. It is quite common to observe cracks in these structures. These cracks are mainly related to stress concentrations or buckling problems. Classic models like plate or shell elements cannot capture or solve all the plate and shell mechanical problems. Therefore, it is important to develop techniques for the analysis of plates and shells.

The conventional plate element representations compromise both the modeling of membrane and bending stiffness of the plate into a single element. Consequently, this compromise results in stress concentrations around holes, stress concentration at the boundary of the plate, etc.

Therefore, for a correct solution yielding realistic stress levels and accurate peak local displacements, a reinforced model, with special treatment should be carried out. These models usually involve plate mesh refinement and exhibit high discrete structure model order. With the model order increasing, it is more difficult to solve problems of larger dimensions.

Each element represents an area of the structure and is defined by the position or coordinates of its corners. Some meshing techniques are usually responsible for the blade model implementation of the concept. These techniques are responsible for the model discretization. A finite element technique called the unit is used for straightforward linear tetrahedra seed mesh. [30][31]

6. Design Considerations for Plate and Shell Structures

primarily describing plates and shells and their functions and characteristics. First, a broad view of plates and shells will be given, followed by a study of the state of such structures in modern engineering. Specific classifications, key points, and static assumptions for plates and shells will be presented. Then, methods to calculate the deflections of plates, including the strain energy method and the convergence stress function method, will be introduced. Differential equation conditions and domain conditions, which are boundary layer phenomena, will also be discussed. The critical buckling loads of columns, plates, or cylinders under different types of loadings will be mentioned too.

Some important points are touched upon, namely a projection of plates over the y-z plane, some practical considerations will be made defining design recommendations. The design for plates and shells can be understood as permitting precise mathematical solutions. Beam structures are mainly simple, easy to detail, and thereby dictate some practical recommendations even when the beam has slender properties. Notably for plates and shells, the detail must be more attentive, taking into account a greater number of possible configurations, the degree of difference between elastic properties, plate boundary proximity, and the production itself, i.e., the construction procedure. It is necessary to perform specific adjustments, whether they are geometric or mechanical, to minimize perforation and deflection due to use. Such conditions are primarily dependent on the anticipated load by the plate. [32][33][34]

6.1. Load Types and Combinations

The magnitude and distribution of different loads to which a plate or shell may be subjected with sufficient accuracy are studied. Specific conditions of the plate's or shell's structures lead to specific types of loads. Most often, the following groups of loads and effects on plates and shells' calculations are presented: concentrated forces and moments of forces, uniformly distributed loads, hydrostatic pressures, and temperature effects. Also, considering the character of objects in modern

engineering, the freezing, creeping, and changing of plates and shells, when time tends to infinity, are of certain interest too. Typical for modern technology are actions up to a certain temperature level, affecting usual loads only when the temperature exceeds the specified values.

From the mechanistic point of view, loads may be divided into two large groups: statically determinate and indeterminate. Statically determinate loads generally include distributed loads, also combined with point actions. Among statically determinate loads are concentrated loads, as well as absolutely distributed loads or those under pressure. In statically determinate conditions for behavior and calculation of these loads, the exact definitions of stress and strain values could apply. This group of loads leads to exact problems which are the initial reference for the application of methods such as the mechanism, finite difference, and finite element methods. In the group of static indeterminate loads, temperature actions are included, as well as hydrostatic pressures. For these loads, the ratio between the sizes of resulting forces and moments needs to be determined only in the elastic region of the material, resulting in some ideality or some task in the assumption of slipping. Basically, at the given temperature, the particular limit load has usually been applied. For these loads, it means that something appears, either another additional physical state or some of the increasing properties of the structure, which may take it off some case not considered. [35][36]

6.2. Material Selection

Material selection in engineering design can be classified into two categories: material selection for a particular part in a given design, and material selection for the whole system during the conceptual design. The first category can be called 'part-material selection', while the second can be called 'system-material selection'. For modern engineering with its interdisciplinary nature, it is vital to conduct 'system-material selection' prior to 'part-material selection', due to the constraints and interactions between parts and other subsystems. It means that materials are not only sought to satisfy the demand of physical as well as mechanical requirements, but are sought to be used in many parts, if not all parts composing the

whole system in order to optimize the whole system or some parts of the system in order to save the structure and to deliver the function and performance of the whole system.

Multi-Disciplinary Optimization (MDO) MDO is the technical foundation of the realization of the global level of material selection in engineering design. Its seven essential components are: multiple disciplines, integrated discipline simulation, coupling connections, systems synthesis technique, optimization techniques, flexible architecture, and heuristic design data. In order to improve the efficiency and reliability of MDO, it is necessary to develop domain-decomposition methodology, design for reliability techniques, design for producibility techniques, and design for maintainability techniques, which are more difficult than the methods for single discipline because they need the incorporation of several remaining disciplines.

Materials and Material Information While the etymology of 'materials' can be searched from Sanskrit, English 'materials' have several definitions. As a noun, they are defined to mean any matter or substance, any physical element, fabric, type of fabric, or substance such as metal, glass, wood, etc. as a material from which things are made. As a transitive verb, they can mean to compose or to form some matter or materials. Splitting from their root, at least five connotation terms can be addressed: basic materials, engineering materials, construction materials, textile materials, and graphic arts materials; where basic materials are the materials of which the Earth is made. Since they are not engineering, construction, textile, and graphic arts materials, which are made from the raw material by a process, in chapters they are addressed as bulk commodities. On the other hand, 'engineering materials' are homogeneous materials or a mix of materials that underline engineering systems, as the most important embodiment of advanced technology. While 'graphic arts materials' include a wide variety of paper, rubber, ink, toner, acetate, and film, 'textile materials' consist of fibers that are either natural or manufactured. [37][38]

7. Case Studies in Plate and Shell Design

Inquiry into present-day plate and shell applications eventually leads to the testing of these structures. It is quite difficult to give definitive answers for a whole range of different plates or shells. A broad catalog of responses is required, since any such situation may occur. As far back as in the seventeenth century, investigations were made into shells from flexible materials and their colorations when subjected to different types of forces such as flexure or inflation. Results were based on practical problems of the time. The theory of elasticity for thin plates was first systematically developed in the eighteenth century. Following this, systematic extensions were made to search for those solutions of the forced equations for deep or shallow shells by which their vibrations could be expressed.

The above partial list of historical facts exhibits an intimate relation between plate and shell theory to its real engineering structure: the enormous development and refinement which has emerged in the following studies of complicated structures justifies regarding shell and plate theory, and similar fields, as peculiar arterial branches in the body of science of structural mechanics. The investigation of plate and shell structures benefits from an abundance of mathematical models and homogenized simplification theories. The best plate geometry model is achieved by an approximate formulation. This represents the required stress singularities at the re-entrant edges. While this model is very efficient in the analysis process, its use in considering the worst-case scenarios of buckling is not suggested. In short, in most thin plate problems, the appearance of stresses at ribbon-like edges is indeed smaller than the stresses within the plate. This is the cause for the interest in modeling only the plate, or each of its finite elements, independently of the rigid body motion. The main result of the model will then just become a detail in its application. The same conclusion holds good for some other full thin plate approximations. [39][40]

7.1. Bridges and Roofs

The most conventional structural application of plates and shells is in the construction of broader

bridges and roofs. The main advantage of the use of a continuous slab is based on the fact that the stress distribution across the continuous slab bridge is more favorable than the distribution of stresses in a simply supported or single-span slab. Most bridge deck slabs used in the construction of medium or long-span bridges are designed integrally with the main structural members such as the girders, arches, or trusses. Continuous slabs, rather than single-span slabs, are advantageous because they contain continuity in both longitudinal and lateral members, greatly increasing their capacity to resist the forces acting near or at the ends of bridge slabs. In addition, continuous slabs are much better at accommodating small vertical or horizontal movements of the piers and abutments. [41][42]

The design of a shell roof may become more efficient through the manipulation of the shape and form of the shell roof structure. The efficiency of a curved dome roof is derived from its ability to act for cyclic as well as earthquake loading as a single uniform continuous shell or space diaphragm. The use of a dome roof or space frame containing a large number of interconnected rods and membrane plates may be more favorable for the support of lightweight treatments of high-capacity wind loads. The dome roofing may be built by a variety of structural systems depending on the span or diameter, the load capacity, and the structural properties of the materials used in its construction. Frequent members include reinforced concrete, steel, and lumber. There are currently several shell roof construction methods that have the capability to support infrequent loading conditions, such as natural snow loads. [43][44]

8. Challenges and Future Trends in Plate and Shell Engineering

Combinations of truss-supported and shear-deformable plates and shells precede the discussion of recent advances and conclude with the challenges and trends of plate and shell engineering, which are also summarized. The demand for lighter and cheaper materials, or designs for components of load-carrying structures in engineering, contributes to the increase in the use of plate and shell structures. However, commonly, plate and shell modeling

strategies are based on complex mathematical theories that make it difficult to pursue accepted practices. Most commonly adopted strategies for determining numerical design and analysis results of a structure include the use of software tools that automatically handle a portion of derived complex mathematical theories. When the assumptions of the mathematical theories do not comply with the design requirements or engineering tests prove that the physical mechanical behavior of the structure violates the assumed properties before failure, then it is necessary to rethink the model. [1][45]

The plate and shell components of load-carrying structures in engineering are often visualized and then analyzed as being quasi-assigned to truss models. This approach conveniently greatly reduces the resources for modeling, analyzing, and rationalizing structural performance to further develop, design, maintain, and upgrade complex systems. Nevertheless, the actual mechanical behavior of plate and shell structures of interest constitutes a balance between the zero bending limit and the bending restrictive limit. This discussion started with a rectangular membrane under tension that was assumed to have the capability of sustaining part of the applied tension on the plane membrane surface. This was then followed by three-dimensional deformation, originated by lifting part of the plane membrane surface, which was assumed and proven to have the capability of sustaining curvature, thus from constant value pure flexural stiffness.

9. Conclusion

This paper concerns the recent developments of plate and shell structures. New materials and structural forms have motivated new activities in application areas such as aerospace, mechanical, civil, automotive, and naval structures. The plates and shells may be subjected to arbitrary loadings, including thermal effects, support motion, and fluid loadings. Thus, active and passive control, wave propagation, non-destructive evaluation, and damage-tolerant design have played important roles in the analysis and optimization of engineering structures. Modern technologies, transformations of variables, asymptotic methods, asymptotically matched asymptotic expansions, deterministic and probabilistic perturbation

techniques, various analytical approximation models, factorization methods, finite difference methods, finite element methods, and special elements have been developed to understand the response of automotive, naval, civil, and aerospace structures. Experiments are being guided by theoretical solutions, and in turn, many theoretical models are being verified.

A collection of recent research papers on the analysis of plates and shells is discussed. All authors agree that the most important future problems remain in being able to completely describe the mechanical behavior of high-performance materials, as well as composite, active, and other advanced structural systems. In fact, it is not until recent years that the enhanced performance capabilities of these structures were recognized or appreciated, and the potential to improve the safety, performance, and capabilities of space and commercial vehicles, naval, civil, and mechanical systems is being actively and aggressively pursued.

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