Chapter 6

Summary, Conclusions, and Suggestions
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The purpose of this chapter is to summarise and evaluate the research work undertaken in terms of the following:

6.1 Summary

(1) Purposes

Given hereunder is a brief statement of the purposes which were sought to be fulfilled in the present work:

(a) To identify the structural advantages of Grid-Nodal-Matrix-Based systems over Gridless-Nodal-Matrix-Based system, which has been documented in terms of axial forces, deflections, contribution, and (+ve) bending moments in the centre of the span, and (-ve) bending moments at the ends, for different values of point-loadings (0-18000 kgs, in steps of 500 kgs, increment) Table no. 3.18 on p. 112.

(b) To assess the shape-effects in contributing structural stiffness (table no. 3.14 and figure no. 3.12 on pp. 102, 103) for five different basic shapes studied in the form of Grid-Nodal-Matrix-Based Stiffeners as strength-contributing factors.

(c) To test different module-sizes (5.25, 10.50, 15.75, and 21.00 meters) for establishing the limiting lengths (CB) Figures no. 3.9a, 3.9b, 3.9c, 3.9d pp. 92, 93 for optimal stiffness contributions in each case.

(d) To establish the limiting lengths for end-stiffeners contributions in terms of modified stiffness and for providing net-relief in overall structural behaviour pp. 84-89.

(e) To formulate a proper discretisation pattern in order to achieve fairly reliable results (pp. 64-71) in terms of computer-time and data-handling work. Also STAAD-III results were compared with another standard software ANSYS (5.3) in terms of Test Problem Study Results for the same model were found matching pp. 72-82.

(2) To achieve the aforementioned purposes, the studies conducted are briefly described below:

(a) Simulated-computer-model (pp. 108-113, 116-125).

(b) Experimental lab model (pp. 136-174).
The experimental-lab-model was developed by casting an RCC model of dimensions (158 x 158 x 110 cms) to corroborate the simulated-computer-model results for deflection and strains parameters at strategic locations.

Six load-levels were taken in variations as: (0, 2500, 5000, 7000, 9000, 10500 Kgs) respectively. Experimental values have got a variation within 5-10% vis-à-vis computer results. Variation in results being marginal can be taken as reliable and consistent, within the limits of practical reasons, scale-effects, and difficulties being faced in realising actual boundary conditions.

Only one set of point-loading applied at critical location has been documented in the present case along with their responses. These responses have been instrumented in terms of deflections and strains for strategic locations.

c) Since it could be possible to achieve fairly reliable-results on computer-models (pp.150-153 and 155-166) further study was conducted on computer-models.

Another representative and analytical model of dimension (15.75 m x 15.75 m) was developed on computer in order to study its responses for a larger-dimension model, for the same set of loadings (0-18000 kgs, in steps of 500 kgs, increment) Table no. 3.19 on pp. 114, 115. Study was done again in terms of axial forces, deflection values, (+ve) bending moments in the centre of the span, and (-ve) at the ends of member, Table and Graph on pp. 126-131.
6.2 Conclusions

(1) Observations

The following phenomena have been observed in the structural behaviour of the newly-developed Grid-Nodal-Matrix-Based system:-

(a) At the macro-level (Overall-Action) the Axial forces/stresses in end-span (beyond junction points, table and figure no. 3.13, 3.16 on p.106) of main active members increase by 40%, with GN (Grid-Nodal-Matrix-Based) system. This increase in value indicates activation of Vector-Active effects significantly. Also, this load-sharing mechanism implies a definite improvement as compared to members subjected to ordinary grid-action (without GN) having Bulk-Active actions.

(b) Here, (+ve) Design BM (Bending Moment) gets reduced at the centre from 10-20%; and (-ve) Bending Moment increases at ends in the average range of 6-9%. So, additional steel reinforcement needed for designing (-ve) moments, from saved steel from (+ve) reduced bending moments, can be used in providing additional junctions-ductility, which may prove beneficial for earthquake-resistant designs.

(c) Furthermore, by using Grid-Nodal-Matrix-Based stiffener, corner gets relieved from stress-results effects by 15% to 20%. This aspect could be very useful for earthquake-affected areas, where corners have a tendency to get severely damaged.

(d) Also, 5% to 7% increase in the stress value of side-columns has been noticed due to Grid-Nodal-Matrix-Based effects. This tendency indicates a shift of load-bearing mechanism from corner-columns towards side-columns, which can be suitably designed.

(e) The use of end-stiffener reduces the deflection values further by 10% to 15% for spans > 15 m, and at higher magnitude of loading.

(2) Conclusions

The following conclusions flow from the above-noted observations:-

(a) Activisation of Vector-Active phenomenon

The study of Grid-Nodal-Matrix-Based-Systems not only brings about activisation of vector-active phenomenon in the end-span but also significant decrease in value of bending-effects for large-span system beyond 15 meters, and at higher magnitude of loading.

This suggests that the use of Grid-Nodal-Matrix-Based-Systems increases significantly the structural efficiency of building design. And such systems can, therefore, replace public buildings, where conventional flat-slab and grid-system, without grid-node (GN), is used normally for medium spans upto 40 feet. Also
related construction activity can be much simplified now, by developing flat surfaces underneath.

Further, in the light of the emerging load-sharing mechanism, such systems can be explored further, as a gateway to new technical horizons for larger-span systems, with a shift from load-sharing, now from predominantly Bulk-Active system requirements to the activisation of Vector-Active behaviour, in addition to net-reduced Bulk-Active requirements. As a result, design and construction requirements are likely to become much simpler, within constraints of present practice and the suggested quality-control checks for better results in futuristic designs in terms of input of resources.

(b) Shape-Evolution Study

For shape evolution, study was carried out in terms of Grid-Nodal (GN) stiffeners in the shape of Diamond-, Circular-, Hexagon-, Octagon-, and Square-shaped stiffeners, around main members intersection point, at \( (a/A = 1/4; b/B = 1/4) \) base formation. Performance-wise, the effectiveness of stiffeners in the shape of Diamond, Circular, Hexagon, Octagon, and Square, respectively, was noticed in the descending order pp. 98-103.

(c) Patterns of Development

Independent study of 4 (four) basic modules of sizes: 5.25m, 10.50m, 15.75m and 21.00, respectively, concludes base-formation pattern as \( (a/A = 1/4; b/B = 1/4) \) or within 10% range, on either side of Junction Point (figures on 3.10 p. 99). This is the most effective pattern of development for significant results; on other patterns of development, it will have less significant contributions.

(d) Computer-Laboratory Model Study

Here, investigation was aimed to corroborate structural mechanism or phenomenon involved for Grid-Nodal-Matrix-Based Systems (analytical results) with the evolved shape. The experimental study corroborates, analytical results within bounds of practical limitations and scale-effects for deflections and strains responses. Hence, diamond-shaped Grid-Nodal-Matrix-Based-System is the most suitable for large-span systems pp. 150-153 and 155-166.

(e) Discretisation Pattern

Selection of proper discretisation pattern is necessary for proper structural analysis of Grid-Nodal-Matrix-Based structural systems. Division of the slab-panel into 4 (four) elements gives fairly reliable results by working on STAAD-III (20.00 and 22.00w versions) softwares. The results have been verified within (90%-95%) by another software ANSYS (5.3) version, on the same model study, selected for comparison pp. 64-71, 72-82.
The structure system or modelled geometry being developed, using Grid-Nodal-Matrix-Based system, has been investigated in terms of deflection patterns, and other stress resultants for two sets of loading: (i) Uniformly Distributed Loading, and (ii) Uniformly Distributed Loading along with Concentrated Loading.

Major findings of the study may be summarised as under:

There is no distinct variation in the pattern of deflection, shear force, and bending moment due to change in the type of loading (due to changed-loading-pattern). However, the magnitude of deflection and bending moment increases in the case of Concentrated Loading along with Uniformly Distributed Loading as compared to those with Uniformly Distributed Loading only.

With the presence of Grid-Nodal-Stiffener effects, deflection and bending moment decrease, but shear force tends to increase. The maximum reduction in deflection and bending moment and minimum rise in shear force occurs, when (a) and (b) are equal or near-equal.
6.3  Suggestions

The following suggestions have been developed on the basis of conclusions, which may be used in future conceptual-formulations of medium-large and large-span structure systems with focus on efficiency of performance, and optimisation of material resources.

(1)  Additional Structural Actions

Additional structural actions suggested for medium and medium-large span-systems or schematic mega-space-forms for unfolding significant-results in future are as follows:-

(a)  Multiple-Grid-Nodal Systems
(b)  Corner-Restraining Effects
(c)  Arching-Action with less rise
(d)  Arching-Action with more uniform rise
(e)  Ladder-Framing System
(f)  Grid-Nesting Effect
(g)  Vector-Active Effects
(h)  Open-Ended Grid-Nodal Stiffeners
(i)  Non-Prismatic Grid-Nodal Stiffeners
(j)  Various combinations of the above for optimal results.

(2)  Scope for Future Extension

As an extension of the present work the following emerging areas/ideas have been identified, and are suggested for future investigations:-

(a)  Similar studies for other spans, and other shapes should be taken up,
(b)  Also Non-Prismatic Sections study work needs to be taken up for optimisation of resources, as in nature,
(c)  Similar studies can be done with concentrated loading acting at some other location on the floor/roof,
(d)  The present investigation pattern may be followed at some other location away from centre,
(e)  Experimental pattern study of the above observation can be made by casting testing model(s) to corroborate the results,
(f)  Temperature study-effects on large spans may also be investigated, and
(g)  Earthquake-load effects may be studied.
(3) **Scope for Future Work (in other related areas)**

For increasing the scope of concept-validation, and for developing universal technological means, many structural systems/patterns can be built and investigated whereby GN (Grid-Nodal-Matrix-Stiffeners) could be studied after implantation, for load-transferring means or sharing techniques in building activities for situations involving large-span spaces. Some indicators are as follows:-

(a) Grid-Node (GN) study effects for skew-grids/systems,
(b) Grid-Node (GN) in steel structures,
(c) GN in raft system of foundations,
(d) GN in floating columns,
(e) GN in twin-effects (Ladder-Framing Technique),
(f) GN in multiple stiffening, and
(g) GN study effect for cantilevered structures.