Theoretical Modelling of Prestressed Nano-Concrete Girder

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Abstract – In recent times nanotechnology has given rise to a new wave of material science in construction industry. *Girders are important structural members in bridges. It provides a link between the deck system and supporting piers, thus helping in the overall load transfer. Strength and durability of girders play major role in the distribution of higher loads. Strength and durability of concrete can be improved by using Nano particles like Graphene and Nano-silica in concrete (Nano-concrete). In this paper Nano-concrete containing optimum % of graphene and Nano-silica is used as material for girder. Finite element analysis of girder was carried out using ANSYS workbench v19.2 to compare load deflection characteristics of ordinary girder and Nano-concrete girder. The FE analysis show better results in Nano-concrete girder than conventional girder.*

Key Words: *Nano-concrete; Graphene; Nano-silica; Prestressed Nano-concrete girder; Finite Element Modelling.*

1. INTRODUCTION

Significant traffic and congestion across urban areas, as well as longer waterway crossings, creates a demand for medium- to long-span bridges. The construction of these longer spans plays a critical role in the development of modern infrastructure due to safety, environmental, and economic concerns. Bridge planning, design, and construction techniques have evolved to satisfy several parameters including feasibility, ease of construction, safety, maintainability, and economy. For over 60 years, precast, prestressed concrete girders have been effectively used in different states across the nation because of their durability, low life-cycle cost, and modularity, among other advantages. These girders are typically used for full length, simply supported bridges. However, there has been a growing need in the transportation sector to build longer spans with readily available standard precast, prestressed concrete girder shapes.

Ashish Birajdar and Chandrakant Pol (2020) gave optimum percentage of Nano-silica and graphene for nano-concrete. Authors stated that nano-concrete has higher tensile strength, compressive strength, Young's modulus, and corrosion resistance than conventional concrete.

Dimitar Dimov et al. (2020) stated that graphene can be used to produce high-performance concrete. Such nano engineered concrete shows enhanced thermal stability, resistance against water infiltration, and mechanical properties than ordinary concrete.

S. Mugil and K. Mugunthan (2019) have studied and investigated the mechanical properties of cement concrete incorporating nano-silica. It has been given that the compressive strength of mortar is increased by adding nano-silica. They studied the performance of nano-silica when it is added to reinforced beam. Finally, the flexural strength of beam was found and load vs. deflection graph was drawn to show the rise and fall of strength.

Abbas AbdulMajeed Allawi (2017) studied behaviour of strengthened composite pre-stressed concrete girders under static and repeated loading. Four pre-stressed I-shape girders of 16m span were casted and tested under static and repeated loading up to failure.

Bhawar P. D (2015) carried out the research work on optimization of pre-stressed concrete girder. The study was carried out to minimize the design process of the bridge system considering the cost of materials like steel, concrete, tendons etc.

Emad L. Labib et. al. (2013) designed nine 7.62m long PSC I-beams made with different concrete strength with the help of a semi-empirical equation developed at the University of Houston (UH). Based on test results, the shear cracking strength of girders with different concrete strength and different shear span-to-depth ratios were investigated and compared to the available approaches in codes such as AASHTO LRFD Specifications (2010) and ACI 318-11 (2011).

From the existing literature, it is seen that several research works have been done for use of various materials and reinforcing fibers in prestressed concrete girder. But there is an evident gap of using Nano-concrete for prestressed concrete girders. No studies have been carried out check feasibility of using Nano-concrete for girders. Prestressed Nano-concrete girder have the potential to provide us higher strength and durable girder than existing girder. It can also reduce transmission length in prestressed girder. So, the present paper highlights the comparison of load deflection curves obtained from the results of finite element analysis.

This paper also gives the comparison of load deflection curves obtained from the results of finite element analysis.

1.1 Nano-concrete

In this research we are going to use Graphene and Nano silica as Nano additives. Previous studies show that addition of Graphene and Nano silica improves the compressive strength as well as tensile strength of concrete. It also increases the young's modulus of concrete. Nanoconcrete reduces the transmission length in prestress concrete. Effective prestress value is more for conventional concrete.

Graphene

Graphene has had very thin layer of carbon, has a higher SSA, high Young's modulus of elasticity, higher thermal conductivity, and greater electrical conductivity. These properties make graphene important nanomaterial in applications of reinforced concrete. Graphene can be defined as single film of carbon atoms organized in a hexagonal lattice. Graphene is fundamental building block for graphite materials of all dimensions. Graphene Nano particles are the extraction of carbon, whichimproves the strength of concrete, but graphene material does not mix properly with concrete directly, beforeadding itto concrete must dissolve with water with the help of SDL.

Table -1: - Properties of graphene

Characteristics	Value
Specific Gravity	1.9
Taste	Tasteless
Odor	Odorless
Color	Black

Nano Silica

Laboratory experiments show that Nano silica particles canbe obtained by sol-gel process from the hydrolysis of tetra ethoxysilane in ethanol with use of ammonia as catalyst. Particle size of Nano silica can be governed by use of alcoholas solvent and changing reaction temperature.

Table -2: - Properties of nano-silica

Characteristics	Value
1. Density	2.7
2. PH	3.7-4.7
3. SiO2 Content	>99.8% by wt.

2. FINITE ELEMENT ANALYSIS

In recent practice, generally prestressed I shaped girders are preferred for bridge construction. The AASHTO standards have specified various types of I shaped girders. They are classified as Type I, Type II, Type III and Type IV girders based on their size and area of cross-section. The proposed FE analysis was carried on an approximately 1/2 scale AASHTO Type II girder (i.e., 5.5m). ANSYS workbench v19.2 was used for FE analysis of girder. For the present work prestressed concrete girder considered to be act as an elastic member like beam. Following figures show the details of the girder.

2.1 Specimen Details

The cross section of the tested girder consisted of two 13.2 mm diameter low-relaxation prestressing strands with minimum ultimate strength of 1860MPa. The strands were tensioned to 75% of their specified tensile strength and placed 5 cm above the bottom fiber of the cross section. In addition, two 16mm reinforcing bars were placed 5 cm below the top fiber of the cross section to counteract the concrete tensile stresses at time of prestress release. 10mm Z-shaped bars were also placed transversely to resist shear stresses.
Transverse shear reinforcement was designed to ensure flexural failure under a two-point-bending test. The beam was longitudinally symmetrical with respect to its mid-span. Figures 1 and 2 show the geometry of the section, placement of reinforcement and prestressing strands, and spacing of shear reinforcement along one half of the beam.

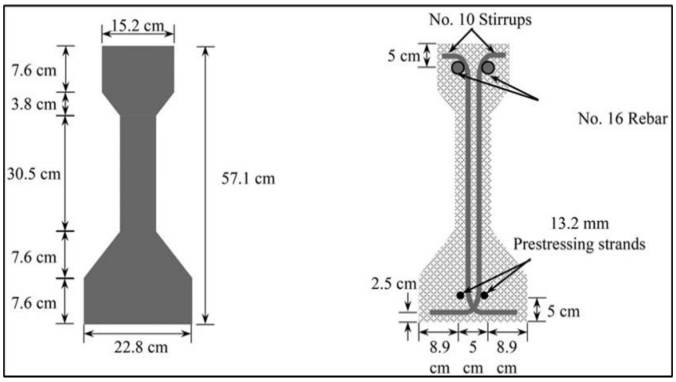

Fig -1: Cross section of girder

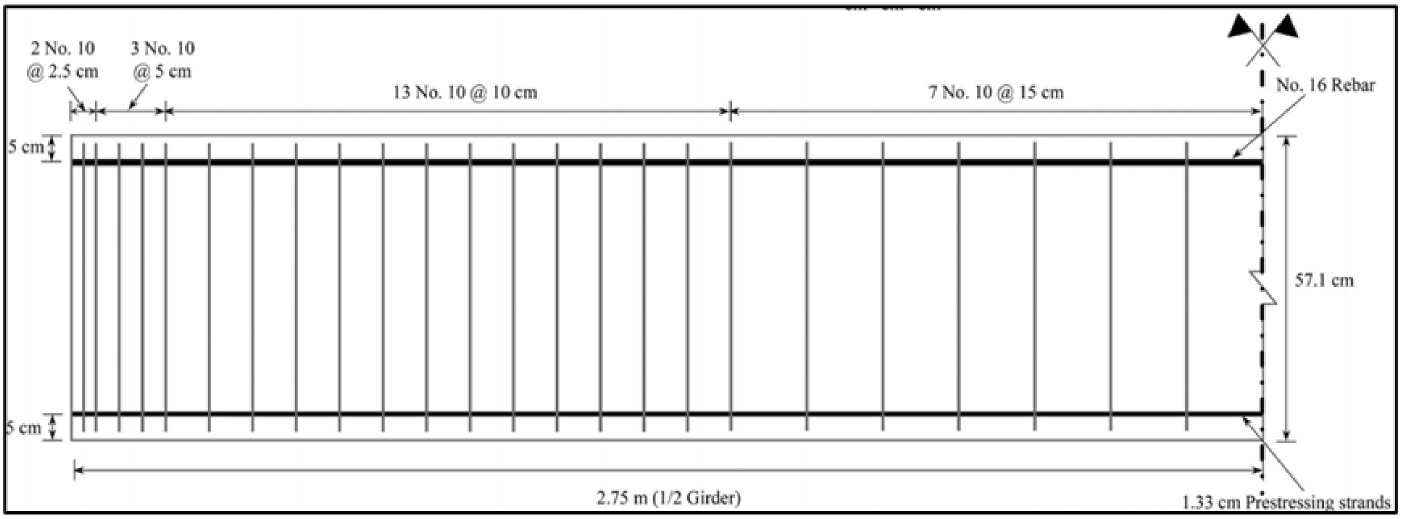

Fig -2: Reinforcement detailing

The properties of concrete and reinforcing tendons used in girder are given Table 1 and 2, respectively.

Table -3: - Properties of concrete

Properties	M45 Concrete	Nano-concrete
Young's Modulus	36690 MPa	41175 MPa
Poisson's Ratio	0.2	0.25
Coefficient of Thermal Expansion	$1.2x10^{-5}$	$1.2x10^{-5}$
Ultimate Compressive Strength	45 MPa	62 MPa
Ultimate Tensile Strength	5.2 MPa	6.3 MPa
Density	25 kN/m^3	25 kN/m^3

Table -4: - Properties of reinforcing tendons

Young's Modulus	196000 MPa
Poisson's Ratio	0.3
Minimum Yield Strength at 1% extension	180.1 kN
Ultimate Tensile Strength	1860 MPa
Density	78.5 kN/m3

2.1 FEM of Girder

For modeling of girder, primarily geometric model of girder was assembled in ANSYS v19.2 and then the FEM was made. The solid model of girder was made in ANSYS v19.2 and then it was discretized by using 20 node brick elements. The FE model has been used to study effect of using fibers on various parameters and better study structural behavior of girder.

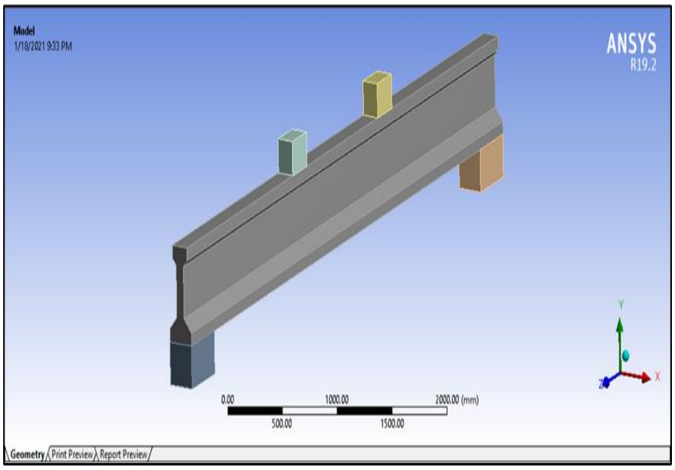

Fig -3: ANSYS Model

The finite element meshed model is shown in Fig 4.

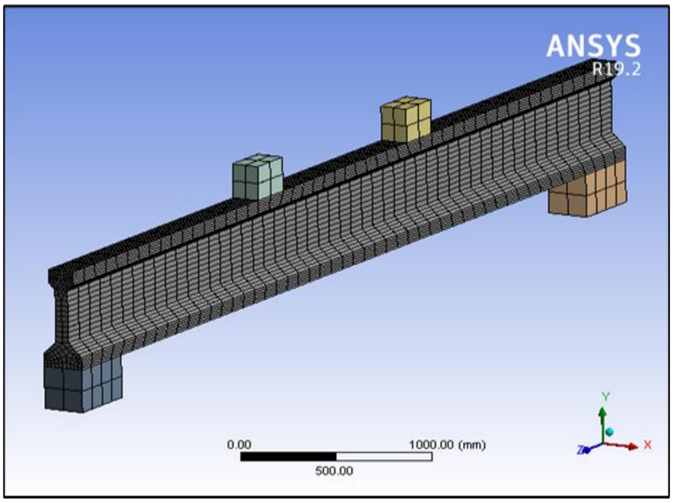

Fig -4: Mesh model of girder

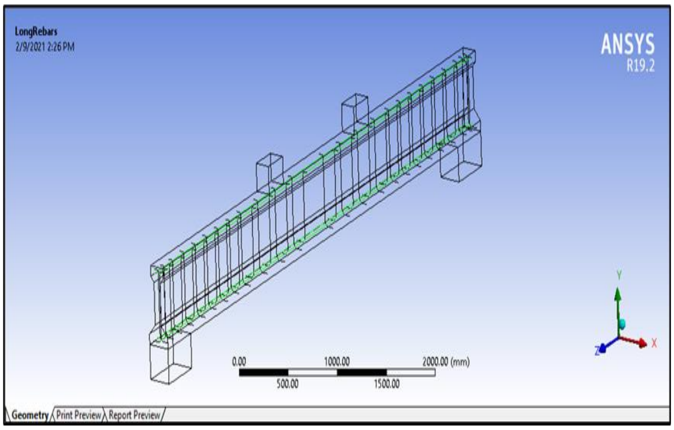

Fig -5: Reinforcement detailing

2.2 Loading Conditions

The loading phase consisted of 3 loading runs of monotonic tests (i.e., variable amplitude loading). For monotonic loading tests, the load was applied at a constant rate until a predefined maximum load level was reached; this maximum load was then kept constant for 5 minutes to allow beam inspection. Next the specimen was unloaded at a constant rate of 13.4 kN/min until fully unloaded.

Table -5: - Applied Load

Load Case	Max Applied Load (kN)	Duration (sec)
1	45	440
2	67	440
3	180	875

The loading rate for the first two load cases was 13.4 kN/min and that for the third case was 22.3 kN/min.

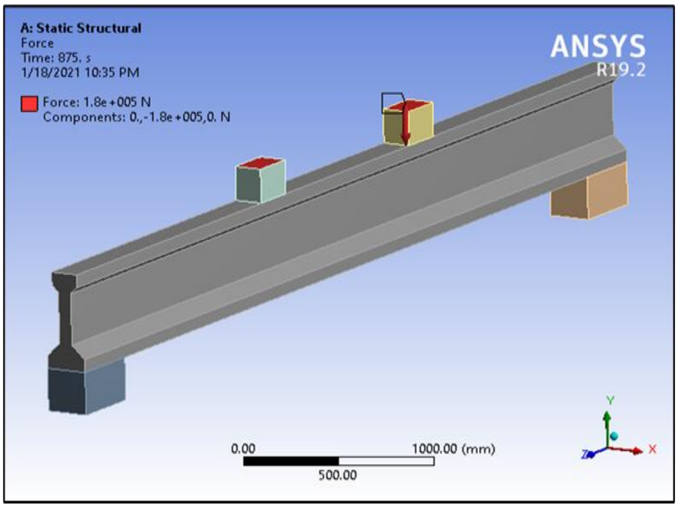

Fig -6: FEM of the girder with loading conditions

Fig. 3 shows the results of total deformation due to static loading in PSC girder.

2.2 Deflection

Maximum permissible deflection for I girder is limited to the span length divided by 250 (L/250). Therefore a 5.5 m span girder can deflect as much as 22 mm in adverse conditions. In this case the loading applied is two-point load and the recorded maximum deflection is 0.58 mm.

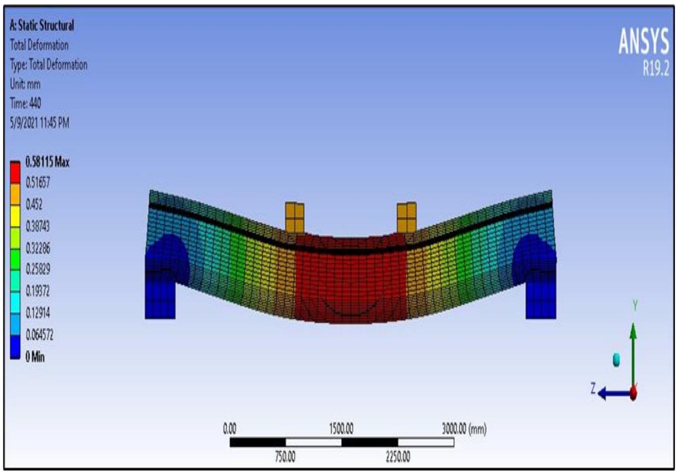

Fig -7: Total deformation

Table -6: - Total deformation

Load (kN)	Conventional concrete	Nano concrete	% Decrease
45	0.651	0.581	10.75
67	1.129	0.968	14.27
180	10.98	9.41	14.32

The analytical study shows that the deflection in nano concrete girder is less than conventional concrete girder by around 14% for same load.

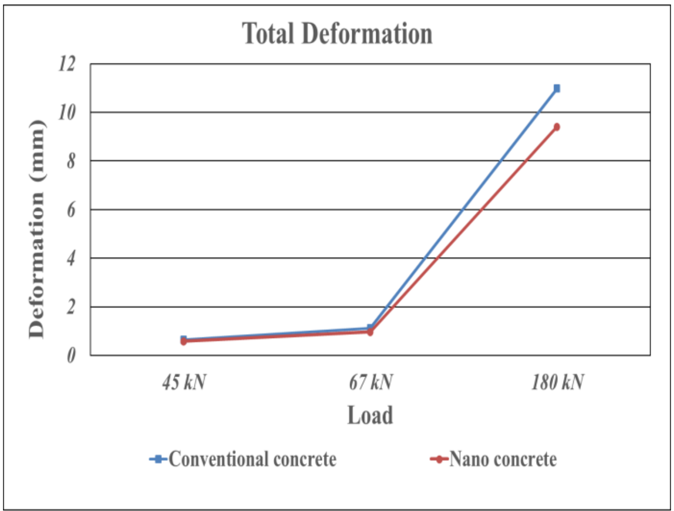

Chart -1: Graph of Load v/s Deformation

3. CONCLUSIONS

1. By using nano-concrete in girder, load carrying capacity of girder is increased.
2. Prestressed nano-concrete girder can result in lesser deflection for same load than conventional girder by around 14%.
3. Prestressed nano-concrete girder has higher yield deflection than conventional girder.
4. By using nano-concrete, the yield deflection of girder is increased by around 12-13%.
5. By using nano-concrete we can reduce the section of girder for same load. Also, we can use same section for higher loads than present loads.

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