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**ORIGINAL ARTICLE**

# Studying the Effect of Trestle design on Distribution of Applied Stresses in 3- Unit Zirconia Bridge using Finite Element analysis

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**ABSTRACT**

*Choosing proper design for zirconia framework can significantly reduce stresses applied on its covering porcelain and improve pattern of stress distribution. The aim of this research was to determine the effect of trestle design in zirconia framework on a 3-unit posterior bridge of maxilla on magnitude and pattern of stress distribution over porcelain using 3D finite element analysis. This research was conducted through finite element analysis. Two teeth of second premolar and molar were mounted in acryl. After teeth preparation, two designs of framework, conventional and trestle were waxed up for 3D scanning. After modeling, the models were loaded according to cusp – marginal ridge occlusion using ABAQUS software. Maximum tensile normal stresses in the porcelain was developed in $S_{22}$ direction which were measured 54 and 24 MPa for conventional and trestle design, respectively. In the framework, these stresses were 130 MPa toward $S_{11}$ direction for conventional design and 100 MPa toward $S_{22}$ trestel design.Using trestle design can decrease tensile stress and improve stress distribution pattern within porcelain in 3-unit posterior bridge of second premolar to second molar in maxilla.*

***Keywords**: Full ceramic posterior bridge, zirconia, chipping, framework design, finite element analysis*

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## INTRODUCTION

Zirconia material was used for the first time in 1990 as endodontic posts and then as implant abutments. This was the starting point of zirconia in dentistry and was later investigated for full coverage frameworks and FPD applications due to its good physical properties, white color and superior tissue compatibility. Moreover, according to in vivo and in vitro studies, considerable attention was achieved by using this material for being under stress regions due to its great fracture strength [1]. Surface properties of zirconia caused some uncertainties about its tendency to absorb plaque, although a 24 – hour examination in 2004 demonstrated that plaque absorbing tendency of zirconia was lower than that of titanium [2].

Despite current applicable and acceptable use of zirconia in posterior ceramic restorations due to its high strength and 100% survival rate [1,3,4], many studies had introduced high amount of chipping as the main problem in zirconia bridges [1,5,6]. The rate of chipping has been reported to be 54% during 3 years [5] and 69% during 5 years [3]. It is expected to occur more in posterior regions than anterior [1]. Meanwhile, this problem is claimed to be more pronounced in bridges rather than single crowns [5,7]. United States Public Health Service (USPHP) and California Dental Association have provided various chipping indexes based on the extent of developed chipping and restoration technique [8,9]. Low thermal conductivity of zirconia [5], small tensile strength of porcelain [3] and also inappropriate support of the porcelain offered by framework with inadequate thickness and incorrect design [10] are some effective factors which increase the risk of chipping. Furthermore, sandblasting the surface of zirconia which used to be an effective solution for this problem is no longer acceptable because it seems that creation of microcracks in core due to sandblasting would weaken the core [5].

There is limited literature about the thermal stress distributions of dental restorative materials. It has been reported that thermal changes are able to create harmful stresses and initiate cracks within porcelains.

The 3D FEA method described as an important tool to predict the stress distribution, assisting in structural design of dental restorations [11].

The number of elements and nodes in our study was very high, but it was the minimum possible value to enable the simulation software to identity geometrical shape of the samples. Therefore, although a great number of elements have been used in this study, application of optimum number has also been observed in this regard.

Analysis of stress distribution was proved useful to indicate physical reactions of restoration, for instance addressing regions with the highest probability fracture [12].

Some researchers argue that FEA studies are not extendable to the clinical condition and their main objectives remain in comparing stress distribution in samples with each other due to some default presumptions such as homogenous and isotropic nature of materials [13]. However, in most FEA works, which have been examined for their brittle materials using normal stress analysis techniques, the amount of maximum tensile and compressive stresses will be compared with ultimate tensile and compressive strength values. Moreover, some other studies directed either experimentally or by finite element analysis, demonstrated proximity of FEA and in vitro results [14,15,16].

Since improvement in framework design can modify detrimental tensile forces in the porcelain [7], taking into account propostion of trestle design by Mr. Miller for decreased stress in the bridge [17], current research was done to study the effect of trestle design on stress distribution on 3- unit finite element analysis and assuming the effect of trestle design in decreasing stress of a bridge.

## MATERIALS AND METHODS

Finite element analysis (FEA) technique was adopted in this research.

First, a natural maxillary premolar and a molar tooth were selected and mounted in an instant transparent acrylic base. Then the teeth were prepared according to a full ceramic posterior preparation (1 mm round end shoulder preparation at axial surfaces and 2 mm at occlusal surface). Then the casts were made out of abutments impressions and waxed up in two different designs (conventional, trestle). The conventional design was 0.5 mm thick in all of the surfaces and the trestle one was a framework with 0.5 mm thickness and a shoulder in palatal surface which is 2.5 mm in height and 1 mm wide, and obeyed a scalloped design in connector regions according to trestle design. Width of the connectors was≥9 $mm^2$ [18]. Afterwards, 3D scans were made using Rexon and Romer apparatus with accuracy of 10-15 μm. the porcelain was also produced with 1.5 mm thickness in accordance with the amount of preparation and thickness of the framework.

Geometrical shape was sketched and the models under study were meshed of the 3D scans prepared from samples (Table 1) (Fig 1,2).

Then, calculational operations were run using ABAQUS software by supercomputers of Mississippi University due to geometrical complexity of the samples. The samples were later exposed to loading according to marginal ridge cusp occlusion [19] as depicted below:

Second premolar: 265.10 N in three vertical components each 88.37 N on palatal cusp and distal and mesial marginal ridges [13].

Pontic (replacement for first molar): 284.04 N in five vertical components each 56.81 N on palatal cusps, distal and mesial marginal ridges and central fossa [13].

Second molar: 271.69 N in five vertical components each 54.39 N on palatal cusps, distal and mesial marginal ridges and central fossa [1].

For approximation of simulated models to clinical realities, 2 parameters of elastic modulus and Poission's ratio were used according to the previous research (Table 2) [11, 20].

It should be noted that all constituents of the simulated models are considered isotropic, homogenous and linear which are just for simplification of the calculations, as consistent with previous studies in this field.

 

Then, the pattern for stress distribution was depicted and since the substance of materials used here were really brittle, normal stress analysis technique was adopted [21] to calculate them in MPa unit.

**RESULTS**

The maximum normal tensile stress in porcelain and framework with trestle design has decreased in comparison with that of conventional design and this reduction was noticed significant in porcelain (Chart 1).

The maximum tensile stress applied on porcelain was decreased in all directions for trestle design as compared with conventional design. The greatest tensile stress was observed for porcelain in $S_{11}$ direction, being 53.7% lower in trestle design than conventional design. Studying stress distribution patterns in this direction indicates the effect of trestle design in uniform distribution of stress within the porcelain. (Fig 3,4).

The amount of tensile stress applied on the porcelain towards $S_{22}$ through connectors's region was 17 MPa for conventional design with the stress distribution being completely tensile (stress with positive coefficient) and it was 9 MPa for trestle design which shows a decrement in comparison with the conventional design. (Fig 5,6).

However, a great portion of this area also indicates compressive stress of 13 MPa. Therefore, the effect of trestle design on conversion of tensile stresses to compressive ones is evident in addition to the decrease in tensile stress of this region. (Fig 7,8)

The amount of maximum tensile stress applied in $S_{11}$ direction within conventional framework is located in distal margin of premolar. The greatest amount of tensile stress for trestle design is observed in mesial margin of 2 nd molar, buccal connector of 2nd molar and pontic which in trestle design was 42.31% smaller than conventional design. (Fig 9,10,11,12)

Since the tensioin is exerted along mesio_distal direction on buccal and palatal margin of the retainers, tensile stress in these regions were assessed within framework design toward $S_{22}$ direction. It was observed that the amount of tensile stress applied to buccal and palatal margins of the retainers with trestle design dominates the conventional design.

**Tabel 1. Number of nodes and elements in the conventional and trestle design**

| | Porcelain | Framework |
|---|---|---|
| Conventional | Node: 37587<br>Element:163979 | Node: 7856<br>Element: 32977 |
| Treslte | Node: 24539<br>Element: 105601 | Node: 7633<br>Element: 32030 |

**Table 2- Properties of materials used in the models**

| | **Elastic modulus (GPa)** | **Poission's ratio (μ)** |
|---|---|---|
| **Feldspathic porcelain** | **67** | **0.3** |
| **Zirconia (Cercon)** | **210** | **0.3** |

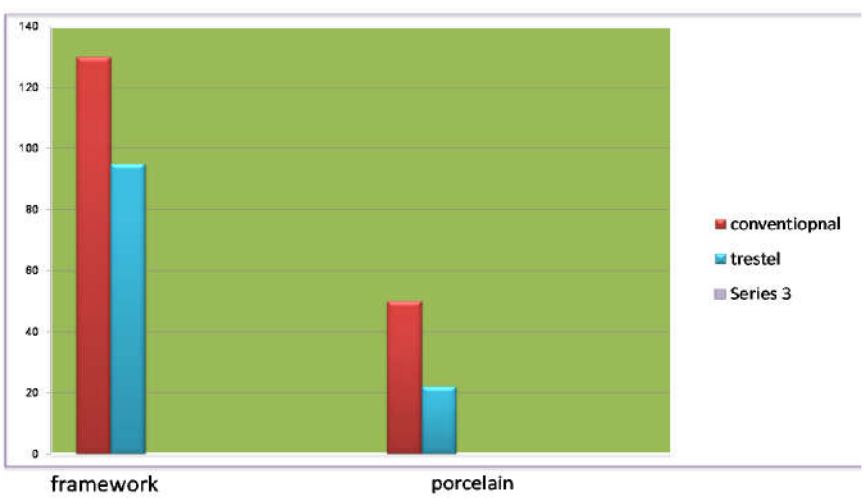


Chart 1- Comparison of maximum normal tensile stress on porcelain and framework within trestle conventional design.

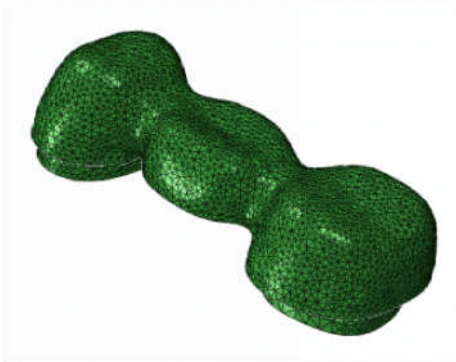

Figure 1.Conventional design meshing

Figure 2. Trestle design meshing

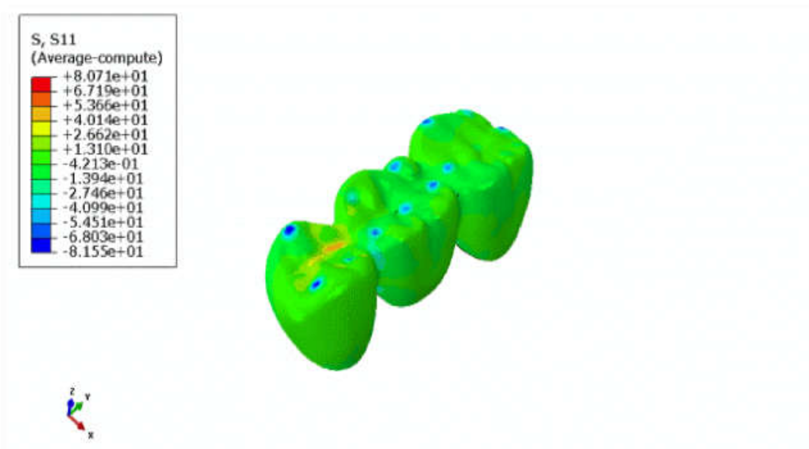


Figure 3. Stress distribution in porcelain with conventional design in S11 direction from occlusal view.

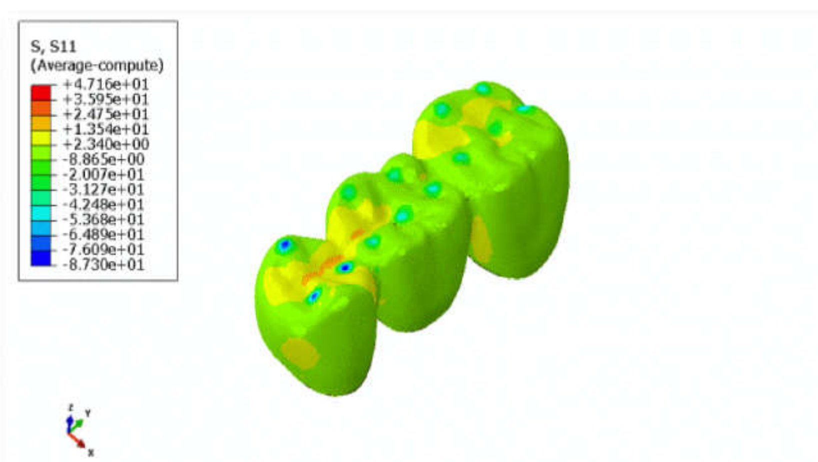


Figure 4. Stress distribution in porcelain with Treslte design in S11 direction from occlusal view.

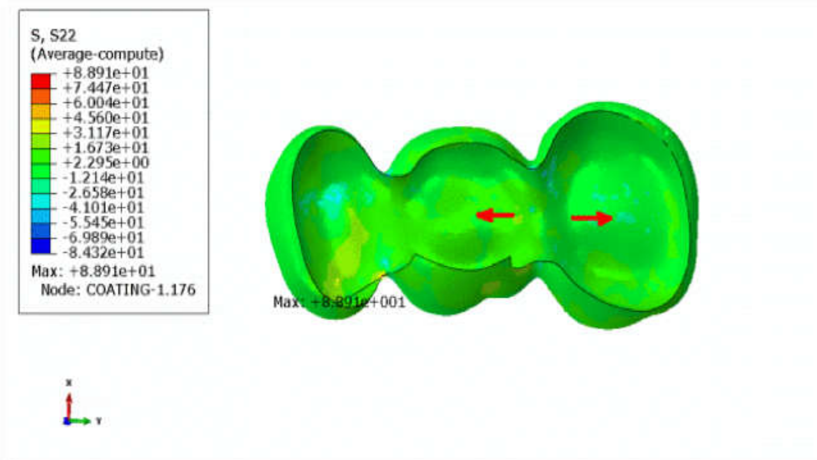


Figure 5. Stress distribution in porcelain with conventional design in S22 direction from internal view.

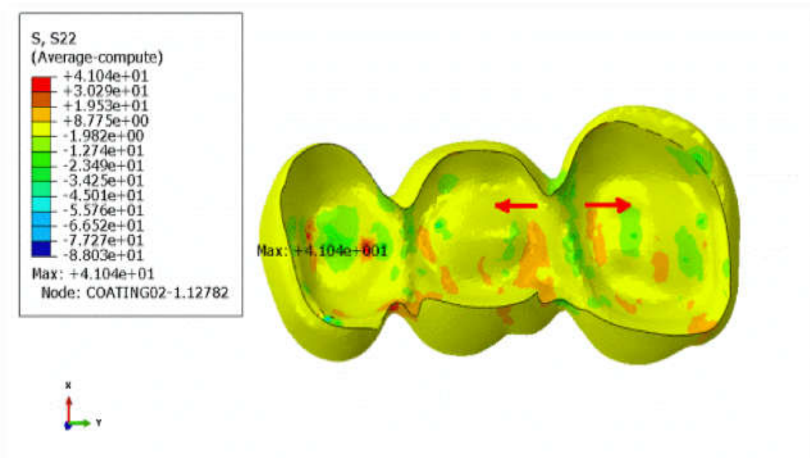


Figure 6. Stress distribution in porcelain with Trestle design toward S22 direction from internal view.

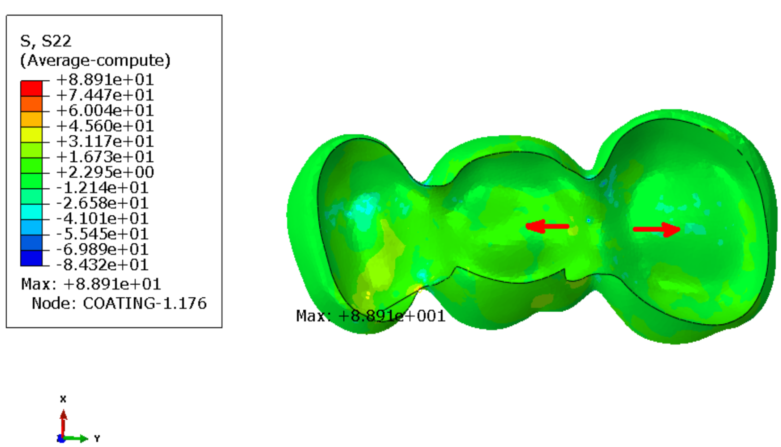


Figure 7.Stress distribution in porcelain with conventional design toward S22 direction from internal view.

 

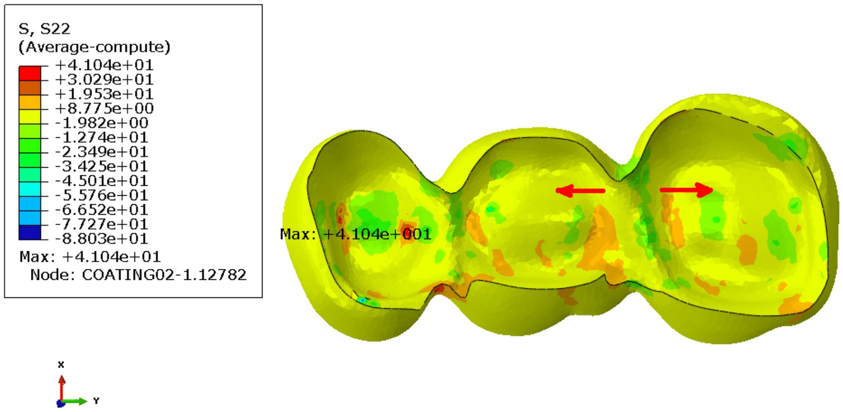


Figure 8.Stress distribution in porcelain with trestle design toward S22 direction from internal view.

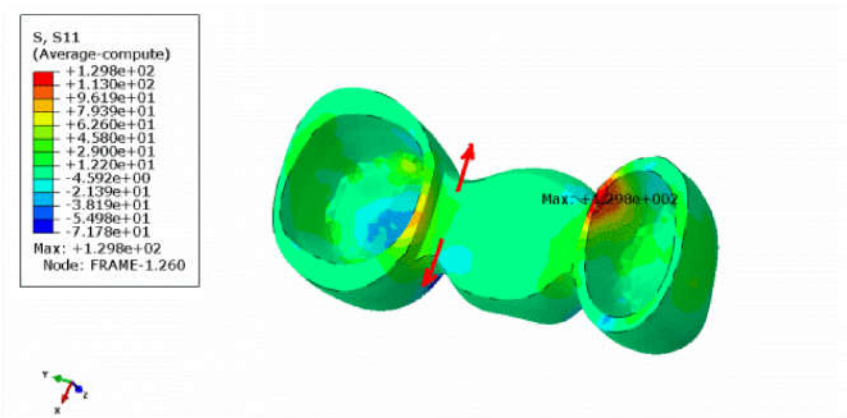


Figure 9. Stress distribution in framework with conventional design toward S11 direction from internal view.

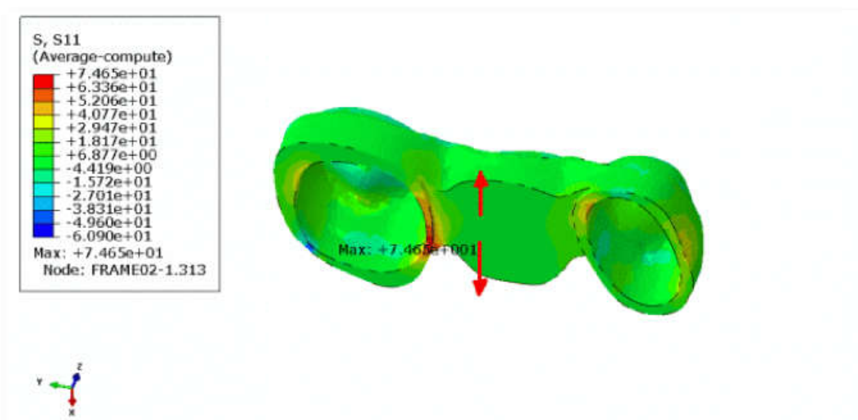


Figure 10. Stress distribution in framework with trestle design toward S11 direction from internal and palatal view.

## DISCUSSION

For accurate results, samples of this research were first prepared in vitro and then 3D scans were made from them. Then the patterns were modeled by using the proper computer software (ABAQUS) .

Results of this research indicate that the maximum tensile strength (applied toward $S_{11}$ direction to the samples) in porcelain which covers framework with conventional and trestle design were 54 and 25 MPa, respectively. Based on the results from previous works which have addressed ultimate strength of various feildspathic porcelains covering zirconia framework [22] tensile stresses of porcelain in conventional design were even greater than ultimate strength of lava Dentin porcelain which has the

highest strength among all other types of porcelains (48.4 MP). This means that there would be possibly a failure in this region (distal of occlusion surface in premolar) and because of the supporting framework, this failure might be chipping of the porcelain.
Investigation of stresses toward S22 direction in conventionally designed porcelain yields tensile stress of 31 MPa in the distal part of occlusal surface in premolar teeth, exactly the area that undergoes tensile stress of 54 MPa during $S_{11}$directoin experiments. This can raise the probability of chipping risk for the porcelain in this restoration to a great extent. In this regard, trestle designed porcelain gives the greatest stress in buccal slope of mesiopalatal cusp in 2$^{nd}$ molar equal to 19.5 MPa. Since this area was known by previous studies as one of the areas with high chipping risk for full ceramic bridges having zirconia framework, the positive feature of using trestle design in zirconia framework can be pointed out. Not only using such a design would reduce tensile stresses of the porcelain in comparison with the conventional framework, but also the palatal shoulder in trestle design would be able to avoid development of superficial cracks in this area, and hinder their combination and creation of chipping. This was also consistent with implications of some other researches, which used to introduce the proper support of porcelain zirconia effective in reducing chipping risk [3,8,10].
Furthermore, comparing the stresses along $S_{22}$ direction in trestle framework with those in conventional framework reveals that the tensile stresses developed in connector's area has increased 74% investigation on stresses in the porcelain toward $S_{11}$ and $S_{22}$ directions demonstrates that the tensile stress in the porcelain covering connector's area for trestle design has decreased to amounts lower than uniform distribution .
Meanwhile, the tensile stress might have been converted to compressive stress (Figure2), which is believed to be more tolerable by the brittle materials.
Taking into account the viewpoints of some researcher who have recognized intervention in framework design as an effective factor in decreasing chipping of the porcelain covering zirconia framework, it can be declared that the proper design is one which uniforms stresses within porcelain [21] and transforms tensile stress exerted on porcelain to compressive stress [3]. According to the results, there is much more uniformity of stress distribution in trestle design in comparison to conventional design. Since tensile strength of zirconia is 10-11 times greater than that of porcelain, it is strictly suggested to select such a framework design in which tension could be applied on zirconia instead of porcelain [23]. Again in comparison with conventional design, trestle design transfers the tensile stresses to framework, thus decreases tensile stresses on porcelain and reduces the failure accurance. It can be judged that to attain these objectives using trestle in zirconia frameworks would be useful.
Studying stress distribution pattern in framework along $S_{22}$ direction puts forward this significant finding: the maximum tensile stress on framework toward mesio distal direction in conventional design is exerted on connector's area, its magnitude is 87 MPa which is acceptably far from ultimate strength of zirconia which is 138MPa [20].
In comparison with conventional design, trestle design with proper thickness in contours can transfer lower amounts of tensile stress to underlying porcelain. Although in both designs lineangles and contours bear the maximum stress, trestle design decreases the stresses significantly.
It should be mentioned once again that all these results require verification by long-term clinical results and in vitro experiments of fatigue test.

## CONCLUSIONS

Taking into consideration the conditions and limitations of this research, the following results were achieved for using framework with trestle design instead of conventional design for full ceramic 3 – unit zirconia posterior bridge:
1. The amount of tensile stress exerted on covering porcelain of zirconia framework was decreased by using trestle framework.
2. The pattern of stress distribution in using framework of trestle design shows a more uniform distribution rather than concentration in one point as compared with that of conventional design.
3. Framework with trestle design causes tensile stresses to be transferred to the framework and thus, they modify tensile stresses applied one the porcelain.
4. Finally, using framework of trestle design is preferred over conventional design due to converting tensile stresses to compressive ones.

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