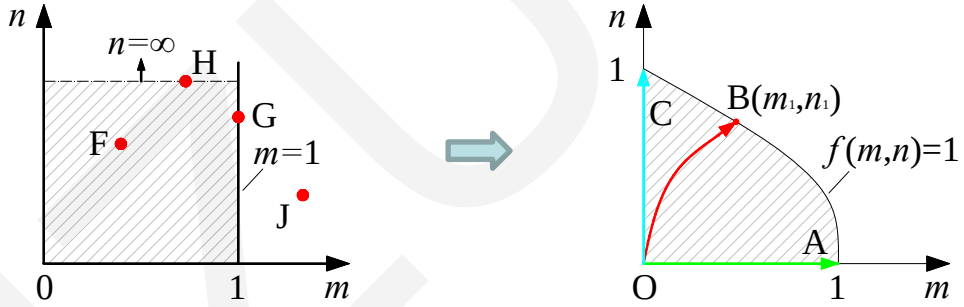
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A new approach to simulate the supporting arch in a tunnel based on improvement of the beam element in FLAC^{3D}

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Background

Tunnel support problems are becoming much more serious. Arch supports are the main support form in tunnel engineering such as mining roadways, traffic tunnels, subways, and water conveyance tunnels, but can not work well sometime as shown in Fig.1.

There is an urgent need to study and solve the arch support problems in tunnel engineering.



Fig. 1 Arch support failure cases in tunnels

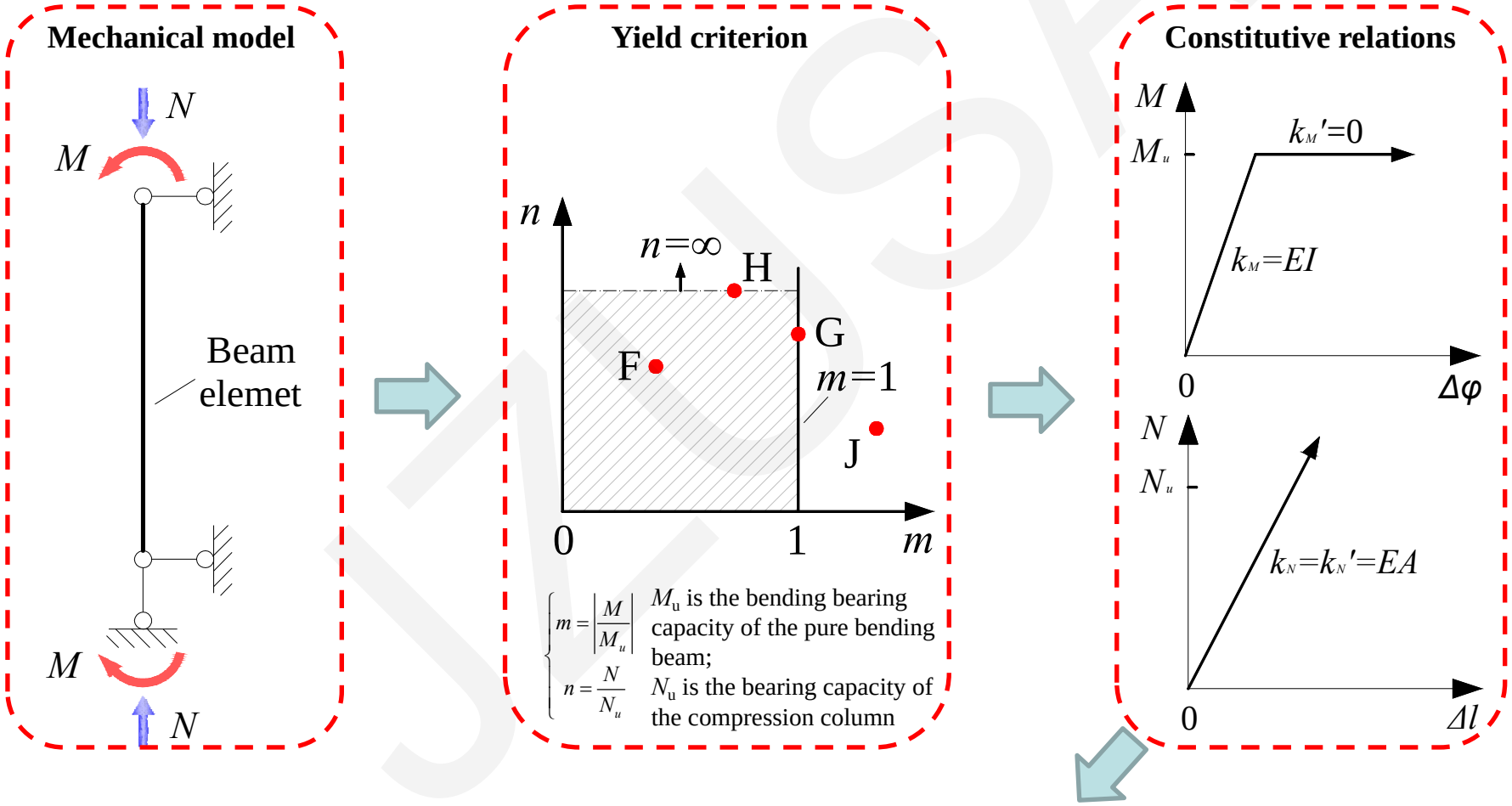
(a) arch leg buckling on the left sidewall in a tunnel supported by I-steel arches; (b) arch crown buckling in a mining roadway supported by U-steel arches; (c) huge deformation in a mining roadway supported by CFST arches

Numerical simulation is a powerful means to perform the above-described research, FLAC^{3D} is a widely used one with the beam element in FLAC3D used to simulate the supporting arch in a tunnel. However, **the original beam element has a shortcoming, which limited the application.**

We made up for this defect through our research presented below.

Shortcoming of the original model

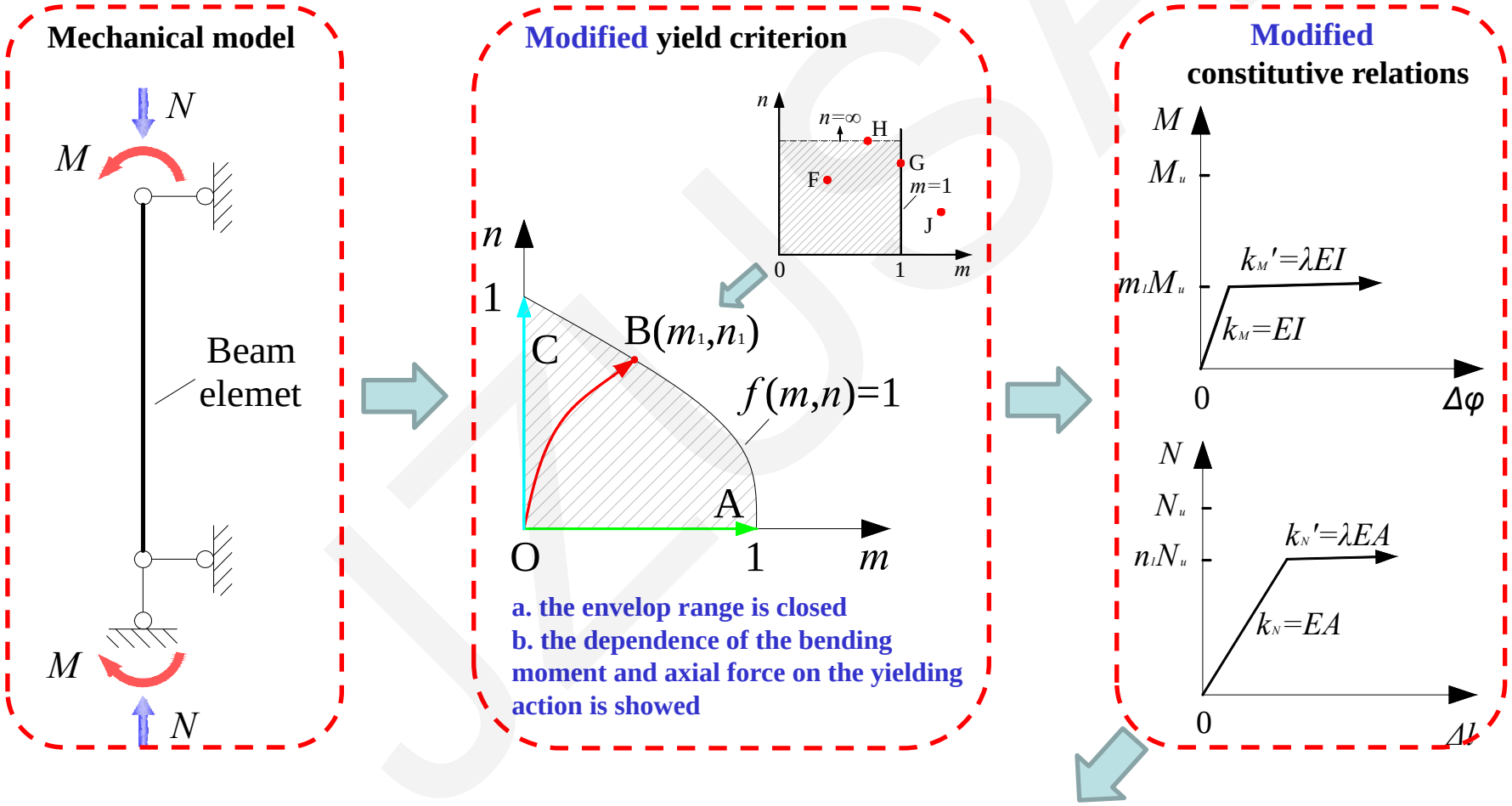
Mechanical model of the original beam element subjected to compression-bending loads



The beam element can yield only on the aspect of bending behavior, and there is no limit in the axial deformation

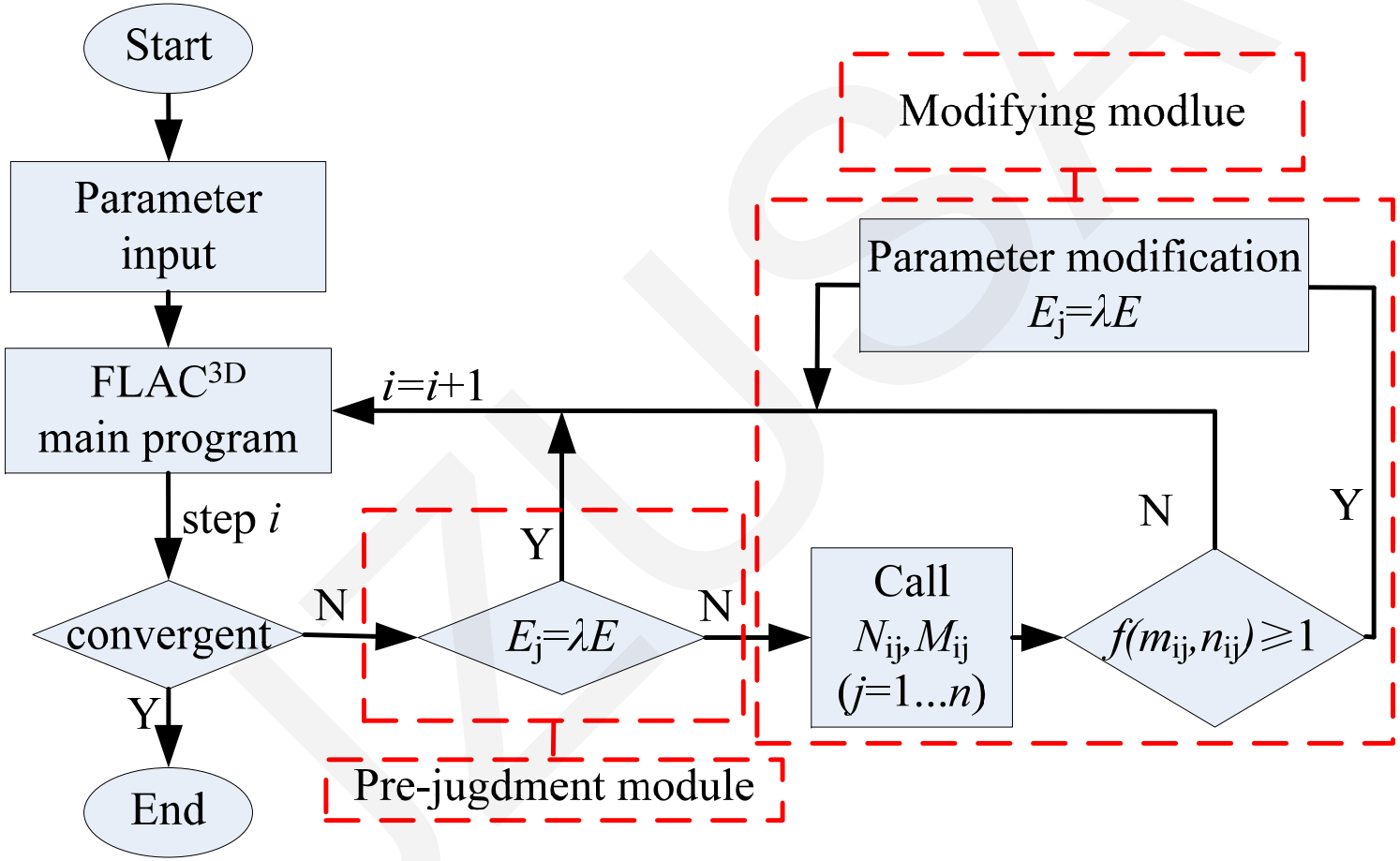
Modified model

Mechanical model of the original beam element subjected to compression-bending loads



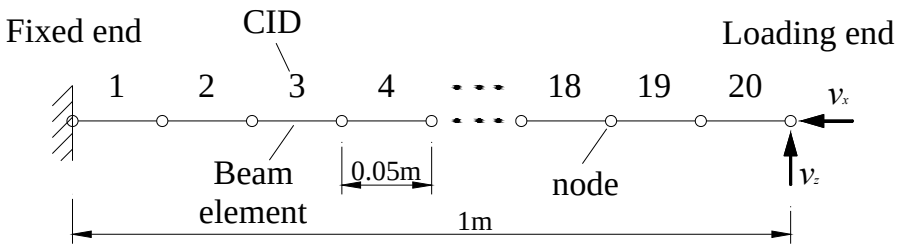
This model can accurately describe the nature of the deformation and yielding failure of the segment subjected to compression-bending loads

Implementation program



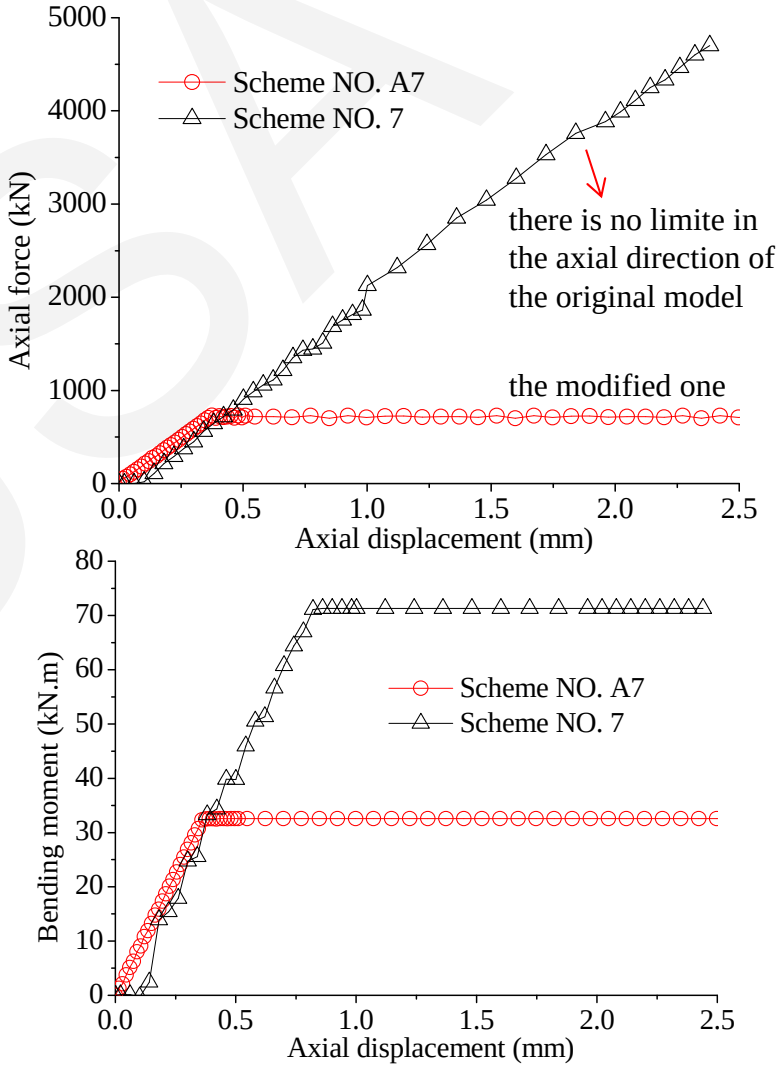
The modified model is implemented through the **FISH language programing**

Verification 1 - Compression bending test



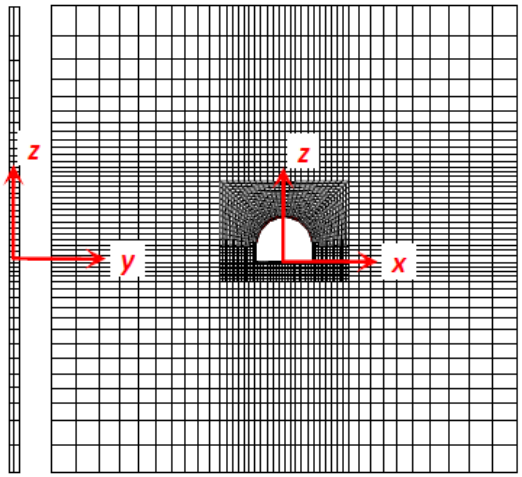
Numerical model of the compression-bending test

- **The bending ability and compression ability are isolated in the original schemes, and there is no yielding point in the compressive deformation, the compression-bending bearing capacity of the original model was obviously exaggerated.**
- **The dependence of the bending moment and the axial force on the compression-bending member using the modified model was revealed by the calculation results, and the behavior of the modified model was found to be in good agreement with reality.**
- **The implementation program is effective and sensitive.**

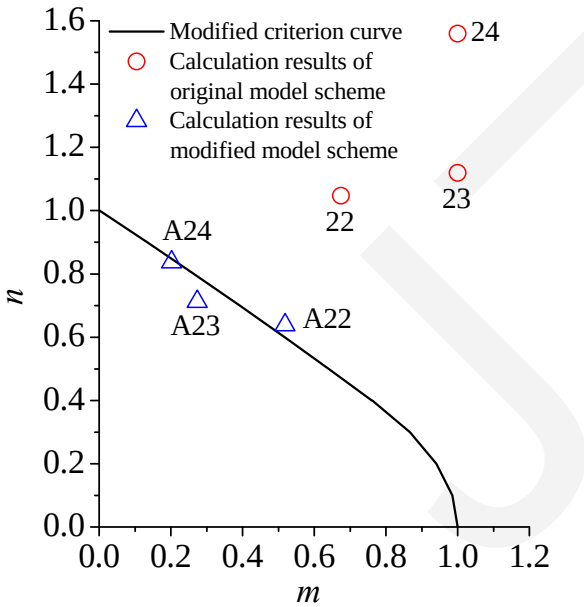


Inner force – displacement curves of schemes NO. 7 and NO. A7 as (a) bending moment – axial displacement curves and (b) axial force – axial displacement curves

Verification 2 - Tunnel support simulation

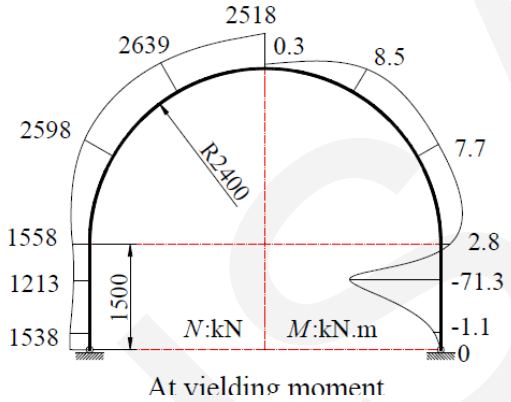


Numerical model of a tunnel with arch support

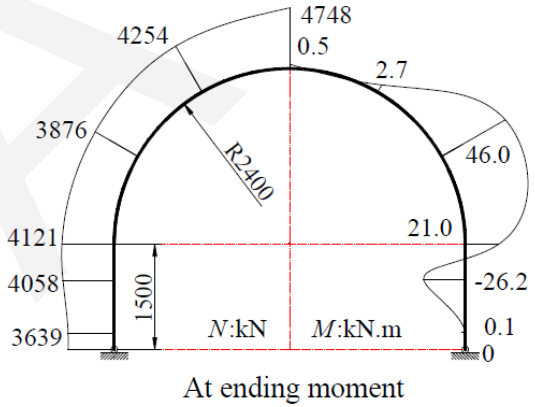


Inner force figure (*m*-*n*) of the critical sections of each scheme at yielding moment

Scheme NO. 23 (original one)

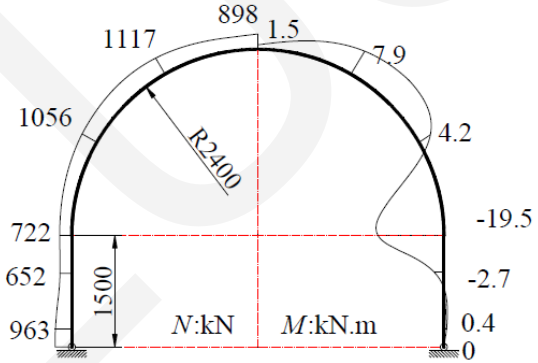


At yielding moment

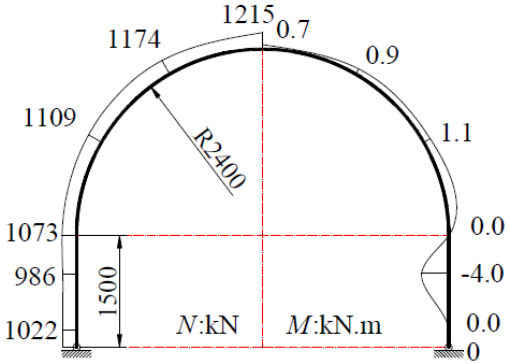


At ending moment

Scheme NO. A23 (modified one)



At yielding moment



At ending moment

Inner force diagrams of the supporting arch in (a) scheme NO. 23 and (b) scheme NO. A23

- **The bearing capacity and surrounding rock supporting effect of the arch model with the original model are significantly exaggerated.**
- **The computing deviation caused by the shortcomings of the original beam element model was effectively suppressed, the mechanical behavior and surrounding rock supporting laws exhibited by the arch model were much closer to reality.**

Conclusions

- Caused by the defect of the original yield criterion of the beam element, the beam element can yield only on the aspect of bending behavior, and there is no limit in the axial deformation. The above shortcoming results in significant amplification of the bearing capacity and the surrounding rock supporting effect of the arch model established by the beam elements.
- To improve the beam element, the yield criterion of the beam element subjected to compression-bending loads was proposed based on the now-available bearing capacity formulas of common compression-bending sections, and the modified model was embedded in the FLAC^{3D} main program based on the FISH programming language.
- Compression-bending tests were performed, and a roadway tunnel arch supporting example was analyzed. The results show the following: (a) the modified model showed the dependence of the bending moment and axial force on the yielding action of the beam element under compression-bending loads; (b) the implementation program is effective and sensitive; and (c) the computing deviation caused by the shortcoming of the original beam element model was effectively suppressed, the mechanical behavior and surrounding rock supporting laws exhibited by the supporting arch using the modified model were much closer to reality, and the calculation accuracy and design reliability were improved.