A SIMPLE FINITE ELEMENT MODEL FOR PREDICTING THE BEHAVIOUR OF HYDRAULICALLY POWERED COALMINE SUPPORTS

by
Brian G.D. Smart
Peter W.H. Olden

ABSTRACT

A scheme is presented whereby the complexities of design and operation of a hydraulically powered coalmine support are modelled using the finite element method. This enables predictions to be made of the interaction of the support with its environment in a variety of operating conditions. The model is a two dimensional representation.

The modelling scheme was applied in two case studies. In the first, the performance of a four leg support was updated by increasing the front leg force. The finite element model enabled changes in overall support performance to be verified. In the second case study, the change in lateral force developed by a four leg support was assessed with changes in support operating height and floor foundation stiffness.

The modelling scheme is capable of further development with the possibility of extending the model into three dimensions and the addition of control elements that would enable an actual mining sequence to be represented.

INTRODUCTION

The prediction of the action/reaction developed by the modern powered support with hemispheric linkage, complicated steel fabrications and inclined legs is a complex problem, particularly as the behaviour of the support is influenced by the foundation characteristics and lateral movement of the roof and floor [1]. A simple finite element model which takes into account the essential characteristics of the support and its surrounding environment is seen to be a useful tool in the support specification process.

Changes in load on the support arise from a variety of sources including roof lowering and caving, floor upward movement, debris compaction and time during the production cycle. A model of a number of supports has been constructed using the ANSYS finite element program [2]. The general approach adopted is applicable to other types of support and could be used to compare their suitability in different mining situations particularly with regard to the prediction of the forces generated on roof and floor at the time of support setting.

The Model

The model is constructed by referring to a drawing of the support. A dimensional side view layout suffices provided it is augmented by cross-section properties (eg. "T" values) for the base, canopy and mechanism which are routinely calculated by the manufacturer, component contact areas and leg tube bores and pressures. Ideally some mechanism focus data is useful as a check that at least the geometry has been set up correctly.

1. Professor, Department of Petroleum Engineering, Heriot-Watt University, Edinburgh, Scotland.
2. Research Associate, Department of Petroleum Engineering, Heriot-Watt University, Edinburgh, Scotland.
The models were essentially two-dimensional beam and spar element models with only in-plane bending and extensions considered. This does not represent the full modelling capability of ANSYS but provides a method whereby the structural behaviour of different supports can be compared, on the basis of reasonably readily available manufacturer's data. The models comprised the following types from the ANSYS program library:

- **STIF54 2d**
  - tapered unsymmetrical beam
  - (for base and canopy)

- **STIF1 2d**
  - spar (for links)

- **STIF3 2d**
  - elastic beam
  - (for shield and "rigid" connections)

- **STIF2 2d**
  - interface (for floor and roof "foundations")

The STIF54, tapered unsymmetrical beam elements were defined to coincide with the contact surface of the base and canopy, but were assumed to act at an effect determined from the height of the neutral axis of the section. The main variables were thus the beam "T" values which were given at significant structural points, and major changes in cross-section. Intermediate values were determined by interpolation. The axial stiffness of these elements was taken to be very large.

The remaining structural components, ie. shield and links, were represented by beams and spars respectively. Again the former was assumed to only react in bending whilst the latter, pinned at either end, only in the axial direction. Rigid connections were assumed to exist between the various pivot locations and their nearest node on the appropriate component. The result of these and the above simplifications is that only overall component displacements and forces are likely to be accurately represented, while detailed stresses are not represented.

The node spacing along the base and canopy was derived by dividing up the distance between "keypoints" to the nearest 100mm. This gave a reasonable resolution to reaction force profiles, enabled uniform foundation stiffnesses to be assumed without too much inaccuracy and did not result in an excessive number of nodes, producing a "simple model". The normal stiffness \( k_n \) of the STIF12 interface foundation elements was determined from the relationship:

\[
k_n = (k_0 \times A_P) / h\]

where \( k_0 \) is the foundation modulus of the surface, \( A_P \) is the contact area and \( h \) is the number of nodes representing the surface.

The foundation modulus and in turn \( k_n \) is a sensitive parameter in these models as these will affect convergence of the nonlinear elements. Typical values range from 20 to 1000 MPa/m as determined from bearing plate tests at underground sites [3], with the former representing a very soft foundation and the latter a hard foundation. This data tends to be imprecise and in the absence of definitive information, foundation moduli are best kept as reasonably low as possible to aid convergence.

The overall geometry of the model was defined so that a "support" could be set at any operating height by changing the lower link angle. Loading was by means of a thermal expansion of the spar elements representing the leg(s). The temperature rise corresponded to the leg pressure.

**Case Study 1**

In this study a comparison was made of the performance of four leg supports before and after reconfiguration to improve their setting capability against broken roof and the yield load rating. This was achieved by increasing the diameter of the front legs and reinforcing fabrications, hence the resultant setting force was moved nearer to the face, and increased from 410 to 510 tonne. The characteristics of the floor and roof foundations were adjusted so that the behaviour of the model was similar to that observed in an underground test on a support before overhaul. These same characteristics were then used to test the model of the reconfigured support. The two versions of the support configuration are shown in Figure 1.
The overall geometry of the models was defined so that they could be set at the 1.5m operating height by changing the lower link angle. Loading was by means of a thermal strain applied to the spar elements representing the legs. A dummy coefficient of thermal expansion was used based on the leg tube bore. The loading for each model was by means of 500 psi pressure increments (temperature) applied to the leg elements with 10 iterations allowed for convergence in each step if required.

In the first part of this exercise the model of the pre-overhaul support was loaded against floor and roof foundation stiffness of various values in a manner representative of the underground test that had been carried out. This required setting the front leg at various pressures, then increasing the rear leg pressure and observing the change in canopy rotation. This was done for front leg pressures of 2000 psi and 5000 psi, attained in 500 psi increments and for rear leg pressures from 0 - 5000 psi also in 500 psi increments. The result of the test for a floor of 100 MPa/m and roof of 50 MPa/m is shown plotted against the corresponding experimental data in Figure 2. These values of foundation modulus represent a moderately good floor and slightly weaker roof.

It can be seen from the plot that there is reasonable agreement between the model and the underground observations at the higher setting pressures, with these values, but not so at the lower pressures. A significant difference is that the experimental curves tend to be convex upwards while the model curves are convex downwards. The former is indicative of the foundation stiffening with compaction. The model exhibits the opposite characteristic although the curves become predominantly linear as the leg pressures are increased. This may be an anomaly of the “interface” as they are currently set up. However in the absence of any other definitive data it was decided to stick with these values for the second part of the exercise.

The model of the support was modified in the light of the changes made in the reconfiguration. This primarily involved changes to the base and canopy “I” values as a result of the addition of strengthening plates and the up-rating of the front legs i.e. increase in leg tube bore. The results from the reconfigured model is shown compared against the original model in Figure 3. It can be seen from this that for the same leg pressures, canopy rotations are reduced.

Plots of the displaced shape of the support with reaction profiles are shown in Figure 4. From these it can be seen that up-rating the front leg greatly improves the canopy roof contact bringing the zero reaction point 600mm further towards the canopy tip as the front leg pressure increases, and this for an increase in setting load of 24% i.e. 80 tonnes.
Case Study 2

This case study was designed to demonstrate the influence exerted by the foundation characteristics of the floor (and hence pressure distribution underneath the base) on the forces developed by the canopy against the roof. A two leg support was selected, as shown in Figure 5, the floor foundation modulus being varied from 10 to 1000 MPa/m. Typical diagrammatic output for force distributions are shown in Figure 6. The results for the movement of the canopy tip with increase in operating height are shown in Figure 7, demonstrating the effective modelling of the lemniscate action.

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1992.
Figure 6. Displaced Shape and Reaction Profiles of the Support Modelled in Case Study 2
(20 MPa/m Roof Foundation Modulus)

The pressure distributions on the roof are parabolic in shape for the support set at both 1.8 and 2.4m operating height on the 1000 MPa/m foundation with a maximum just ahead of the leg centre and just behind the leg centre respectively for the two cases. For the 10 MPa/m floor the variation of pressure distribution is more nearly linear with maxima at the base toe. For the canopy the pressure distributions are linear in all cases.

The results of running the various cases of support operating height and foundation modulus are presented in Table 1. For the support set at an operating height of 1.8m there is less of a change in applied lateral (shear) force by the canopy on the roof as the floor foundation modulus reduces, remaining reasonably constant at about 0.85 MN (87 tonne). This lateral force is a maximum for the 10 MPa/m floor, 20 MPa/m roof combination. For the support set at 2.4m there is a greater change in applied lateral force as the floor is reduced from 1000 to 10 MPa/m, changing from 1.0 MN (102 tonne) at 1000 MPa/m to 0.80 MN (82 tonne) at 10 MPa/m. From the plots of the displaced shapes of the various configurations of the model these changes in active lateral force can be attributed to the variation of the competing factors described previously, and illustrated in Figure 8.

A further observation that can be made from the results of running the models is that for the support set at 2.4m there is more movement in the canopy zero-reaction point as the floor modulus is reduced than for the support set at 1.8m. At 1.8m operating height the zero reaction point tends to remain at 500 to 600mm from the canopy tip whereas at 2.4m operating height this distance tends to be less and reduce more as the floor is weakened, being 400 to 500mm at 10 MPa/m.

CONCLUSIONS

A simple finite element model of a hydraulically powered coalmine support has been described and its application demonstrated by reference to two case studies. There was reasonable agreement between the model behaviour and measurements made on an actual support underground. The interaction and relation between support behaviour and its operating conditions has been demonstrated.
Figure 8. Characteristics of the Support Modelled in Case Study 2

11th International Conference on Ground Control in Mining, The University of Wollongong, N.S.W., July 1962.
### Table 1. Summary of Results of Finite Element Modelling of Support in Case Study 2.

<table>
<thead>
<tr>
<th>SUPPORT OPERATING HEIGHT</th>
<th>FOUNDATION MODULUS (GPa)</th>
<th>TOTAL LIG FORCE (kN)</th>
<th>BASE</th>
<th>CANOPY</th>
<th>APPROX. DISTANCE ACROSS CANOPY TO LOAD DEVELOPMENT (mm)</th>
<th>REACTION FORCES ON CANOPY NORMAL (kN)</th>
<th>FOR DEBRIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>FRONT</td>
<td>REAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NORTH</td>
<td>WEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>1000</td>
<td>20</td>
<td>4.353</td>
<td>-4</td>
<td>-14.4</td>
<td>2.5</td>
<td>101.1 -13.5</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>20</td>
<td>4.553</td>
<td>3.1</td>
<td>25.9</td>
<td>2.3</td>
<td>16.4 -14.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.553</td>
<td>0</td>
<td>-11.7</td>
<td>2.3</td>
<td>2.5 -3.2</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td></td>
<td>4.553</td>
<td>-1</td>
<td>-11.7</td>
<td>2.5</td>
<td>102.1 -13.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.553</td>
<td>0</td>
<td>-11.7</td>
<td>2.5</td>
<td>16.4 -14.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.553</td>
<td>0</td>
<td>-11.7</td>
<td>2.5</td>
<td>2.5 -3.2</td>
</tr>
</tbody>
</table>

There is considerable scope for extending the features of the model. This might include constructing a three dimensional version which would enable lateral movements of the support to be considered or assemblies of supports to be analysed (at the risk of departing from the simplicity of the current model). Another refinement might be to build in a control element so that the hydraulic pressure might be sequenced as in an actual mining operation.

Further work could also be carried out to more closely represent the non-linear foundation characteristics of the roof and floor (compaction) and in the provision of site data to compare model output against.

### ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support details supplied by Gullick Dobson Ltd. and Meso Mining Equipment Ltd., the assistance provided by management at Prince of Wales colliery and the funding for the work provided by British Coal.

### REFERENCES

Smart, B. G. D., Olden, P. W. H., and Metcalfe, K., “Consideration of the lateral forces generated by powered supports”, to be published in the Mining Engineer, the Transactions of the Institution of Mining Engineers.

