Kidd
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Raise Overhead Protection Design and Certification

WSN Health and Safety Conference

Sudbury Ontario

April 2016

Raises, Open Hole Hazards, and Protection Systems

- **Raises required for ore passes, fill systems, ventilation, and in some cases to provide the initial void in production stopes**
- **Raises can be developed by drilling and blasting, or by raise drilling equipment**
- **Personnel can be exposed to hazards including;**
  - Falling from heights (when working near the top of raises)
  - Being struck by falling objects (when working near the bottom of raises)
- **The need to work in proximity to raises is governed by the intended purpose of the raise**
- **In stopes, production drills need to be operated close to the top of the raise and may need to work near the bottom of the raise, depending on the mining method**
- **Protection at the top from the “open hole” hazard can be by an engineered steel cover, a concrete plug, or by not reaming the raise through to the top**
- **Protection at the bottom of the raise is usually by preventing access, or by an engineered cover when work must be done in close proximity to, or immediately below the open hole**

Overhead Protection

- **When working below an open raise, typical covers have been constructed from**
  - Timber
  - Steel
  - Concrete, or some combination of the above

- **Design considerations must include**
  - The height of the raise
  - The diameter of the raise
  - The inclination of the raise (material sliding down a footwall, vs free falling directly on the cover)
  - The nature of the cover on the top of the raise
  - Accessibility and intended work at the bottom of the raise
  - The size of any equipment which is working at the bottom of the raise and the available room remaining in the undercut development to construct the cover
  - The maximum potential mass of the object which can fall within the raise considering
    - *An object entering the raise through the top cover*
    - *The maximum statistically based mass of rock or ore which could fail from the side of the raise, given the joint and fault orientations and the design diameter of the raise (a wedge)*

Background

- Overhead raise bulkheads have been in use for over 40 years, with no documented failures
- Cover design was questioned following loss of V30 Reamer in 94-061 in late 2014
- Mass of reamer exceeded the “civil” engineering design loads for impact on the historic steel grating and timber design
- Short term remedy was that concrete plugs would be installed where work required below raises until capacity of existing bulkheads or alternative design could be verified
- Concrete causes additional work, and high risk of plugging production slot raises, resulting in less than ideal blasting success

Methodology

- Very difficult to assess impact loading on bulkheads without data
- Civil engineering methods assume factored loads, and “failure” is defined by deflections exceeding 1/360 of the span
- Impact loads vary as a function of the potential energy, which is a function of the height an object drops, as well as the mass
- The mass of a wedge of rock is fairly easy to estimate, based on the known geologic features in the area of the raise, and the diameter and length of the raise, which governs the size of the largest wedge that can “fit in the hole”
- As a worst case scenario, the wedge is assumed to fail from the top of the raise, thereby dropping the furthest distance

Wedge Analysis – 42”φ

Wedge Information

North wedge [2]
Factor of Safety: stable
Wedge Weight: 0.000 tonnes

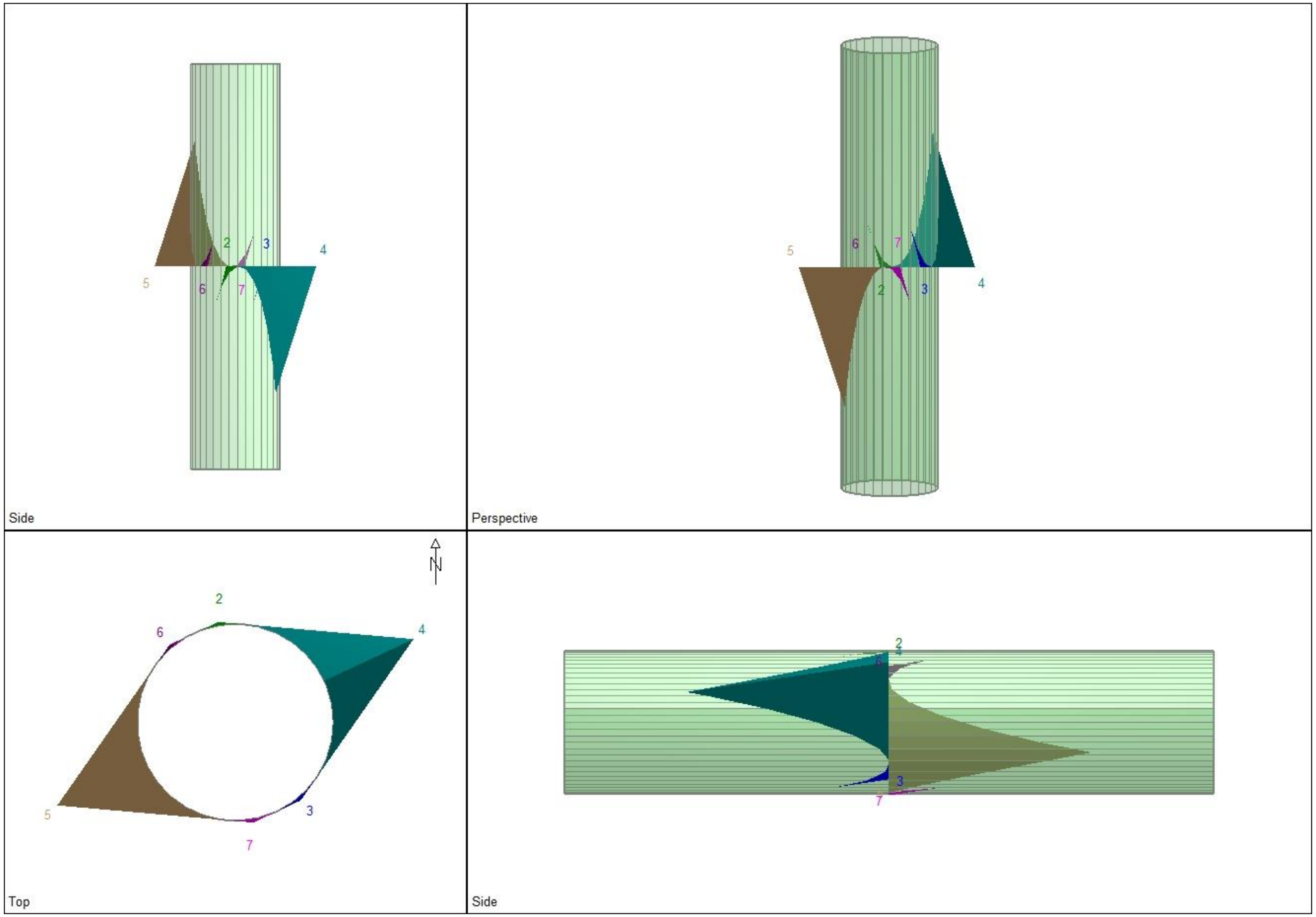
South East wedge [3]
Factor of Safety: stable
Wedge Weight: 0.000 tonnes

North East wedge [4]
Factor of Safety: stable
Wedge Weight: 0.251 tonnes

South West wedge [5]
Factor of Safety: 0.315
Wedge Weight: 0.250 tonnes

North West wedge [6]
Factor of Safety: 0.082
Wedge Weight: 0.000 tonnes

South wedge [7]
Factor of Safety: 0.082
Wedge Weight: 0.000 tonnes



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Drop Tests

- Three test weights designed, when coupled with varying lengths of raise to simulate ‘typical’ impact loadings for maximum wedge failure for most slot sizes
- Typical impact loads must either be resisted by the bulkhead with very limited deflection (civil engineering standards), or allowed to deform to dissipate energy (mechanical engineering methodology, similar to auto crumple zones)
- To fully assess the bulkhead impact resistance, information on the mass, actual drop distance, deflection of the bulkhead during the “arrest” phase, and the amount of permanent deflection must be obtained
- At all times the personnel undertaking the tests must be protected from the hazards

Weights

- **Six test weights manufactured using 20, 40, and 205 litre pails/drums filled with concrete, and equipped with lifting eyes**
- **Weights**
  - 830-840 lbs
  - 230-240 lbs
  - 140 lbs
- **Simulate range of impact energies of rock wedges anticipated to fail from raises of various diameters**
- **By adjusting height from which weights are dropped, the actual impact energy can be modified**

Test Setup

- Weight suspended over open raise from a chain fall to allow drop height to be adjusted
- Quick release hook to allow weight to be dropped without exposing personnel
- Safety line to retrieve weight from within the raise if the bulkhead works, and to prevent the weight from travelling large distance in the undercut if the bulkhead fails

Methodology

- **Data to allow impact energy to be calculated**
  - Mass
  - Drop distance
  - Bulkhead configuration and position before and after impact to determine “permanent” deflection
  - Video of impact
  - Instrumentation to measure bolt loading
- **Analysis of failure mode(s)**
  - Test existing design, under normal “maximum” loading conditions for a 0.76 m or 30 inch raise
  - Document the bulkhead “before and after” and critically assess any failure
  - Modify existing design as necessary, based on findings from tests
  - Completely revise design if the existing design proves to be insufficient

Existing Cover Testing

- Test weights dropped down two raises on conventional and modified grating based bulkheads
- The conventional bulkhead tested was "selected at random" and no special effort was made to ensure the installed bulkhead was in total agreement with the original design drawings
- The timber contained defects which were only discovered at the time the test was being done, therefore this represented a "worst case" scenario
- The bulkhead was tested using a 240 lb weight, dropped through a distance of 35 meters, which represented the worst case scenario for the maximum mass in a 0.76 m diameter raise


Existing Cover Testing

- Cover suffered failure of either bolts or timber
- Underlying cause was the welded steel grating was too stiff, and could not transfer or dissipate energy, resulting in shock loading of support elements
- Timber unable to “flex” rapidly, and flexure was beyond the allowable extreme fibre bending stress, resulting in ejection of splinters which could cause injury

Modified Cover Testing

- The timber was seen to be a “weak link” from the first test
- Timber replaced by heavy gauge flat bar straps, to test the hypothesis that the straps would provide much more flexibility, and be better able to deform
- Straps included “slots” to allow the strap to slide relative to the bolts, in order to absorb further energy
- Bolts were instrumented to try to determine the loading on the bolts during or after the impact
- The data logger was incapable of sampling fast enough to obtain the peak impact load, but should be able to determine the final load or deformation


- 75-S35 – 381 kg falling 23 m – grating failed at rivets, detached from rebar, overloading single strap

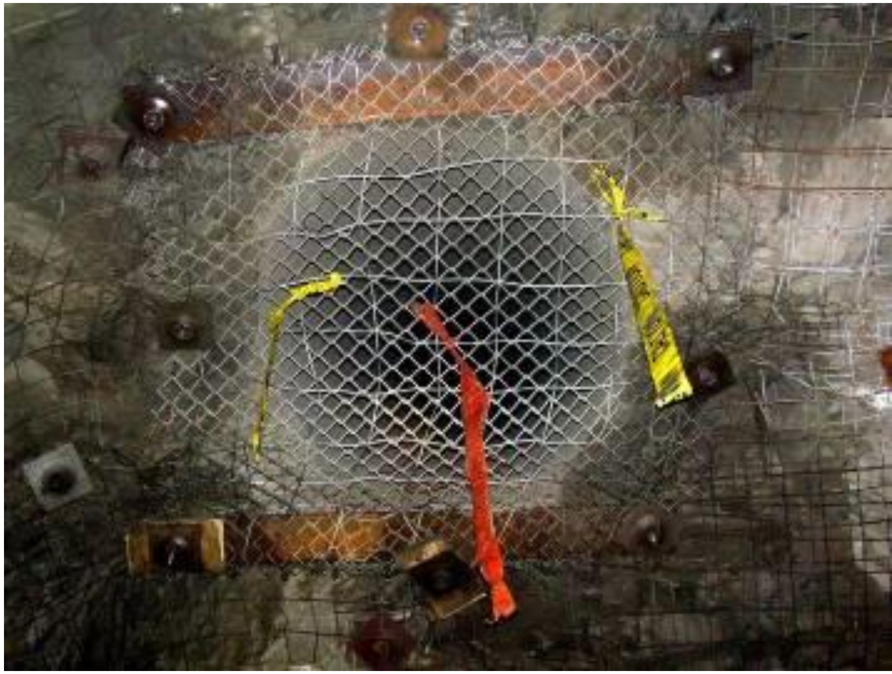
- 94-063 – 108 kg falling 35 m – rapid bending of grating caused timber failure during shock loading

Path Forward

- Revise existing timber cover design to include additional 8 x 8 mid span, and a screen below timbers to catch wood fragments
- Restrict existing covers to V30 (0.76 m or 30 inch diameter) raises, less than 25 m in length
- Any other stopes requiring uphole drilling with larger diameter raises will need concrete in short term
- Develop alternate design through additional tests

Prototype Cable Laced Mesh Design

- Literature search revealed that an alternate design existed within the "corporate memory" from Brunswick Mine
- Brunswick design was insufficient for Kidd operating specifications – design was based on shorter smaller diameter raises, smaller wedge mass and lower impact energy
- Brunswick design also showed evidence of failure of both cable and mesh under lower impact load during the initial certification testing
- The serrated strap used to restrain the mesh had "sharp contacts" and high point loads, which caused the mesh to fail where it was highly confined and unable to yield

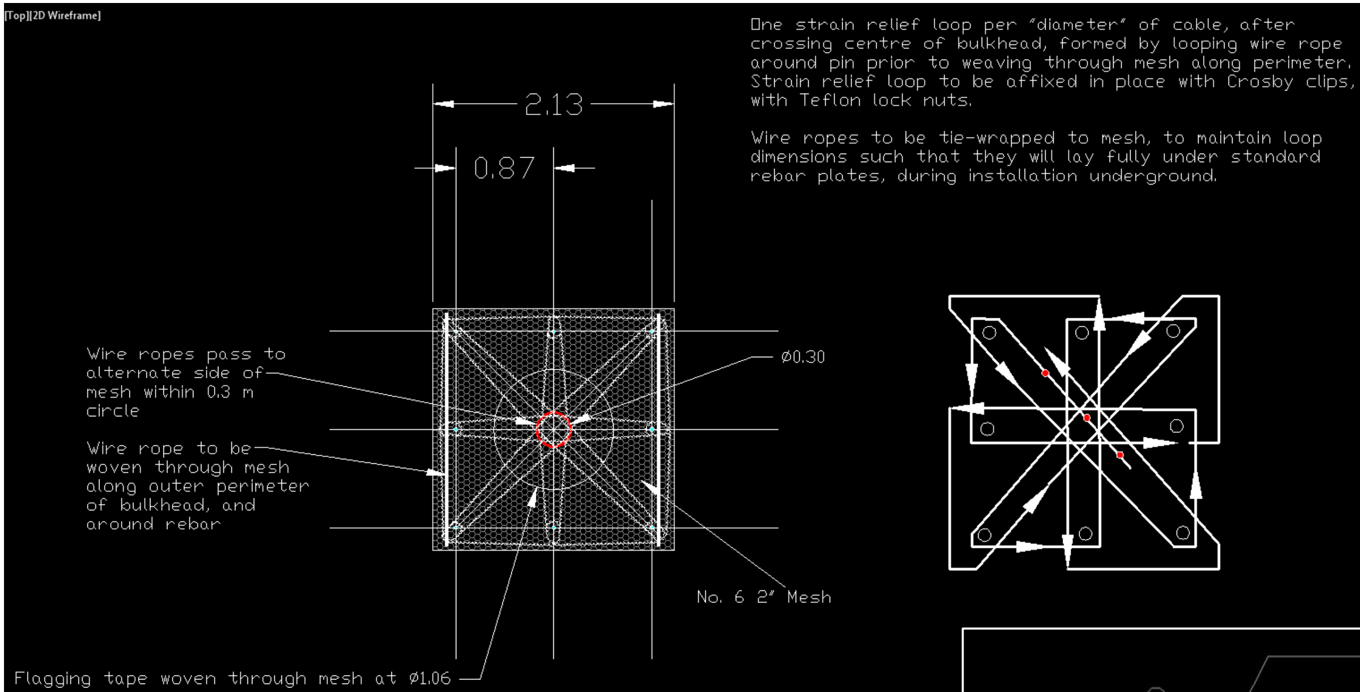


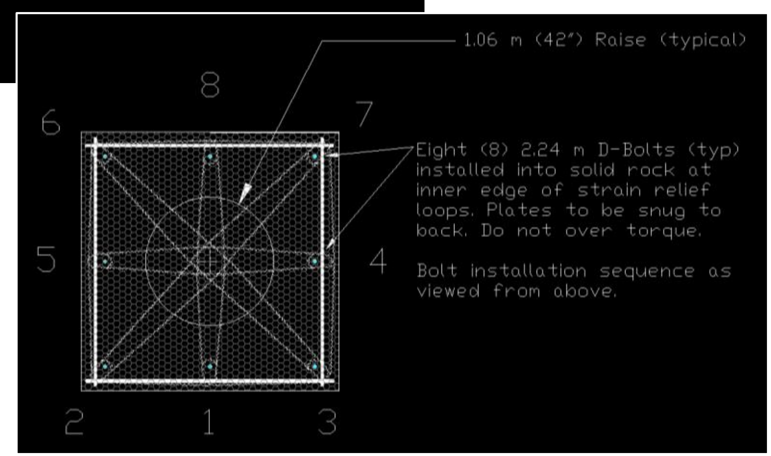
Prototype Kidd Design

- Double the mesh to compensate for the failure observed in the Brunswick design report
- Change the method of weaving the cables through the mesh to increase the yield and strain capacity of the cables
- Provide “shock” capacity in the cables to allow them to slip before they created high loading on the supporting members
- Remove any “sharp contacts” in the system between the cables, the mesh and the bolts, to reduce the risk of the “guillotine” failure seen with the second “modified” bulkhead design at Kidd, and the Brunswick design report, where the serrated strap edge was seen to cut both the mesh wires, and the reinforcing cables

Prototype Cable Laced Mesh Bulkhead under construction 2015-04-13

Fabrication and Installation Layouts





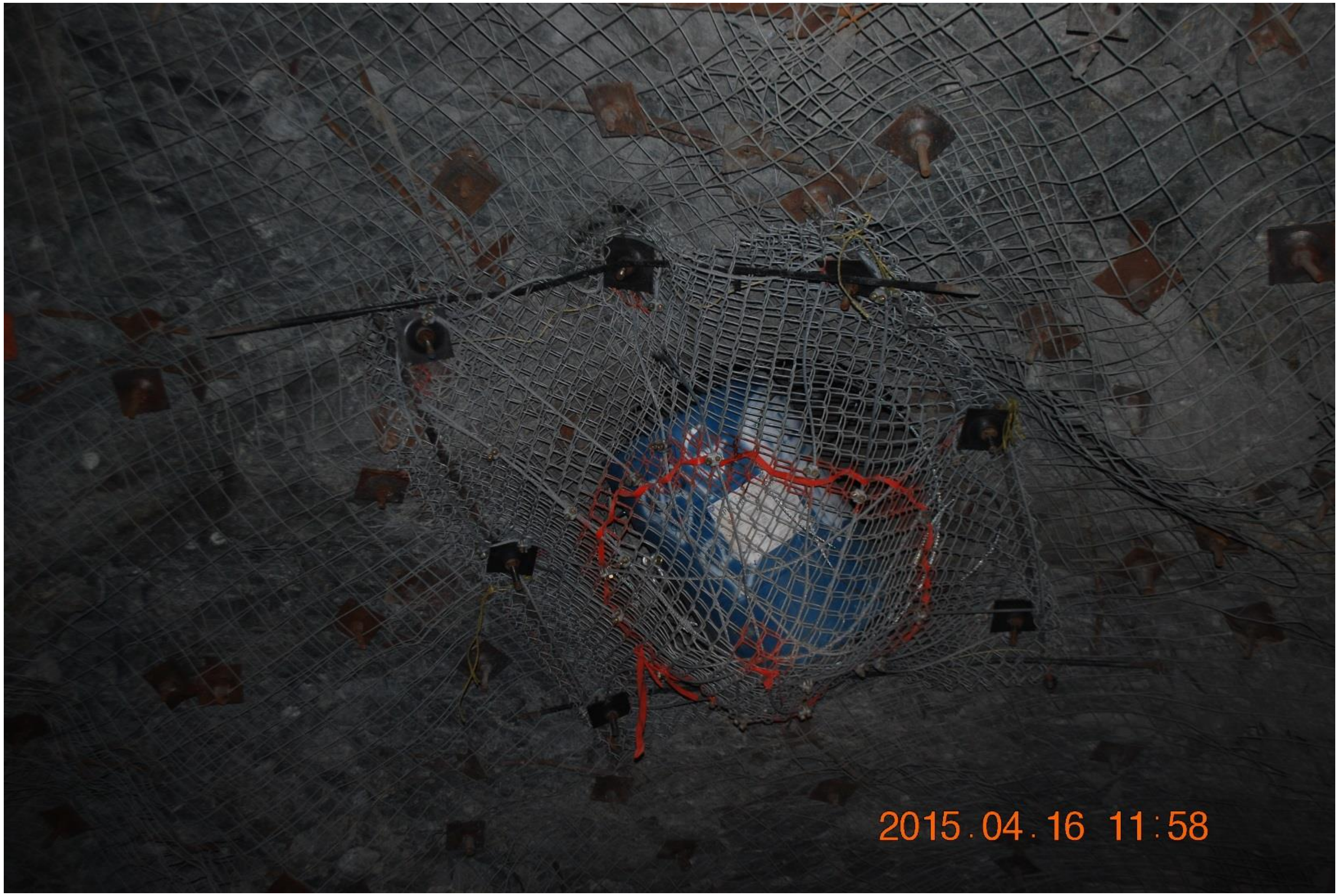
Prototype Cable Laced Mesh Bulkhead under construction 2015-04-13

Note Crosby clips tying rope to mesh in multiple locations

Note tightly coiled strain relief loops intended to encircle bolts at installation

Prototype Cable Laced Mesh Bulkhead 87-086 St, 2015-04-15

87-086 Bulkhead after impact of 381 kg mass, falling 20 m



Analysis

- Wire mesh did not tear at any location, and was successfully reinforced by cables
- D bolts stretched, but did not break
- Several cables broke due to restricted ability to slip caused by excessive number of Crosby clips
- Final impact load was in excess of 535 kN or 120,000 lbs force
- Equal to design load of 250 kg (maximum wedge), falling 35 m, with potential energy of 85.5 kJ, coming to stop within 0.16 m only through displacement of bolts, with FOS of 3.75

Subsequent steps

- **New mesh bulkhead adopted pending further testing to determine ultimate survivable load**
- **Other testing required to determine strength reduction effects of production blast holes being drilled through the mesh at typical design spacing**
- **Means of “mass production” with quality control/quality assurance had to be developed**

Bulkhead on Prototype Assembly Jig

Enhancements

- **Jig table to pivot vertically to reduce strain on workers during assembly process**
- **Strain relief loops to be elongated to provide more "slip" capacity, coupled with revised torqueing procedure for Crosby clips**
- **Crosby clips to include Teflon lock nuts, to prevent nuts loosening prior to installation**

Proof

- New bulkhead installed in the 95-164 Stope, where uphole drilling had to be done near the raise
- Scoop doing cleanup on the overcut lifted the “grating top cover” and inadvertently dumped in excess of 2 cubic meters of muck down the raise

Going Forward

- All raises to include cable laced wire mesh bulkheads when work planned in undercut
- All previous timber and grating designs to be “archived”, due to insufficient impact ratings for raises larger than 0.76 m and heights more than 25 m
- Concrete plugs only to be used where cable laced wire mesh bulkheads cannot be safely installed, as they carry high production risk

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Questions?