On Wednesday June 23d we raised the mast on the ACTS flow loop for the first time. The initial lift worked well. For the sake of safety we used a large fork lift in conjunction with the hydraulic cylinders.

The mast was designed with a number of safety features built-in. The mast and structure were designed to AISC specifications which prescribe the use of a number of different safety factors depending on the nature of the component and the stress. The hydraulic cylinders were splayed outward to provide lateral support of the mast when it is in a raised position. Only one hydraulic cylinder is required from a strength standpoint, leaving one as “spare”. Built-in flow restrictors control the flow of hydraulic fluid so that even if the hoses were cut and the safety valves failed to operate, the mast would only be let down at an acceptable slow rate.

Before the test, several meetings took place between the Project Engineer, Research Technician, and the manufacturer’s representative for the hydraulic cylinders over a period spanning more than a week preceding the test. The hydraulic cylinders had been detached from the mast run out and back in a minimum of 10 times each to assure that all the air had been bled out. Computerized controls had been completed and tested. All the welding was completed by certified code welders. The calculations were re-checked. And a fork lift was hired from Belger Cartage as a matter of safety to follow the mast up on its initial lifts (as far as the fork lift would reach).

As it became time for the test to begin, the appropriate people were assembled, the fork lift was set in place, the street was blocked to prevent any traffic from inadvertently driving close to the area and instructions were reviewed so each person responsible for operating any part of the equipment were clear on their task and where to watch for direction as the test was on-going.
With the assist of the fork lift we raised the mast approximately 8 to 10 degrees. We then continued upward using only the hydraulic cylinders to approximately 25 to 30 degrees inclination. All went very well.

We decided next to lower the mast down and lift from horizontal without the initial assist of the fork lift. While lowering the mast, it moved laterally several degrees. Upon visual inspection, spalling of the concrete on the face of the support pillar, and deformation of the steel support structure was observed.
Since the nature of the problems were so much unknown at the moment, a 40-ton crane was brought in for additional safety and then the mast was then lowered to its original horizontal position.

Loading on the mast can be determined by summing moments about the pivot point “A”. The required force of the cylinders (“B”) to lift the mast from the horizontal position is 140,141 lbs. For two hydraulic cylinders with an internal diameter of 8-inches this equates to 1394 psi. Resolving the loads in the triangle formed by the hydraulic cylinders and the mast equates to a load of 135,741 lbs. horizontal (tension in the mast) and 34,840 lbs. vertical (normal to the mast).
As the mast is raised, stresses in the mast, the hydraulic cylinders, and all attachments decrease. For example, at a raised elevation of 20 degrees, the required force of the hydraulic cylinders reduces to 134610 lbs or 1339 psi which resolves to 132322 lbs. tension in the mast and 24716 lbs. normal to the mast. The point being that the highest stress levels occur just as the mast is lifted from the horizontal position.

During raising of the mast, all performed as expected. During lowering, the mast rotated several degrees (counterclockwise if viewed from above), the structural support warped, and point bearing loads occurred underneath two corners of the support structure causing superficial spalling of the concrete in those areas.
No damage appears to have occurred in the mast itself, the hydraulic cylinders, attachment points for the hydraulic cylinders, the concrete base, the steel I-beam sub-structure, nor the attachment j-bolts, nor the concrete pillar other than superficial spalling on two corners. The support structure is sound and will continue to provide excellent support to the mast for all continuing experiments in the horizontal configuration. The support structure will, however, have to be re-built to be able to operate the mast in any elevated configuration.

There is not one single component or action that stands out as the definitive explanation of failure of the support structure. Certainly in the higher stress condition created during the initial lift of the mast from horizontal, and through continued lifting, no problems were evidenced at all. Quite the contrary, knowing we were past the critical stress stage it was a moment of congratulation that all was going flawlessly. When the mast was begun to be lowered, however, cylinder #1 was obviously favored and torsion was imposed to the support structure to such a degree that it became deformed.

As it became deformed, the front corners (those corners closest to the hydraulic cylinders and resting on the concrete) imposed a point load onto the concrete and caused it to spall off in those areas. As the mast was continued to be lowered, the support structure further deformed, and the mast rotated.

The mechanism which caused cylinder #1 to be favored is complex beyond our means to understand at this juncture. Perhaps when we are able to disassemble the support structure we will learn more. Without any instrumentation on the cylinders to monitor the pressure on
each side of each cylinder’s piston we can’t say absolutely that, for example, cylinder #2 was not receiving any pressure but cylinder #1 was and that caused the torsion. We do know how the hydraulic pump and the valves and lines that go to the cylinders work and we can see that it should not be possible for one cylinder to see more pressure than the other.
It is reasonable to assume that the hydraulic cylinders are not perfectly matched and therefore, even when pressurized the same amount, there would be some minor differences in their resulting force. But this should be negligible and no difference was apparent when the mast was being raised. Also, it is reasonable to assume that the cylinders were not installed with such precision as to be perfectly complimentary to each other and not have any tendency whatsoever to want to push the mast either left or right but this too should be negligible and no difference was apparent when the mast was being raised.

The same could be said for friction in the pivot pin, alignment of the pivot pin to the axis of rotation, friction in the clevis ends of the cylinders and the alignment of those ends.

However, due to the length of the mast there is an opportunity to magnify any tendencies toward misalignment. Also, there was no overt effort to design the support structure for strength against torsion. Therefore, it is our hypothesis that the hydraulic cylinders did not push each at the same rate that was the primary causative problem. Repairs, of course, are dependant on the availability of sufficient budget, however we anticipate that the repairs we will look strongly at would include a support structure which will be resistant to torsion and a means by which the cylinders may be collectively monitored and individually controlled. We will be consulting with others who have experience with hydraulic systems similar to this to help us.

The exact nature of all repairs and modifications are yet to be decided, and ideas continue to come forth almost daily, however some of the ideas have included:

1) Rebuild the support structure with such appropriate changes as to avoid the current damage;
2) Add controls and instrumentation to the hydraulic cylinders to assure that they act in unison;
3) Re-design the lift system to utilize a tower and winch system rather than hydraulic cylinders;
4) Re-design the lift system to utilize a single hydraulic cylinder;
5) Rebuild the mast to result in a lighter lifting load requirement;
6) Re-design the lift system such that the base-end connection of the hydraulic cylinder(s) would operate from a point more directly underneath the mast-end connection thus minimizing tension loads in the mast;
7) Add provisions for crane attachment in the event that, whatever lifting system is utilized happened to fail, a crane could be brought in to assist the mast back to horizontal;
8) Redesign to allow no more than a limited amount of elevation (example: 30 degrees, 45 degrees);
9) Some combination of two or more of the above.
Pluses and minuses of each of these could be seen as following:

1) Rebuild the support structure with such appropriate changes as to avoid the current damage:
   
   Pluses:  
   - Returns the mast to operational status;
   - Avoids previous weaknesses;
   - Relatively inexpensive to do.;
   
   Minuses:  
   - Does not correct any tendencies that the hydraulic cylinders may have for wanting to extend or retract at different rates from each other beyond brute strength of the support structure to prevent it.

2) Add controls and instrumentation to the hydraulic cylinders to assure that they act in unison:
   
   Pluses:  
   - Removes problems with the cylinders operating at independent rates;
   
   Minuses  
   - Additional expense;

3) Re-design the lift system to utilize a tower and winch system rather than hydraulic cylinders:
   
   Pluses:  
   - Could provide a greater angle-of-attachment which would reduce loading in the mast;
   
   Minuses:  
   - Such a mast would be subject to very large forces tending to pull it over, it would require a very massive design;
   - Would probably require a large foot-print;
   - Would probably require guy-wires which would be in the way of existing structures;
   - Would probably limit the angle to which the mast could be raised;
   - Would involve several costly expenditures including the tower, winch, associated tackle, mast modifications for attachment, dead men for cable stays;
   - Inherently less safe than the hydraulic cylinder method because there is no back-up in case a cable breaks;

4) Re-design the lift system to utilize a single hydraulic cylinder:
   
   Pluses  
   - Avoids the two hydraulic cylinder method which could have a tendency to impose torsion;
   - Reasonably easy to do with materials at hand;
   
   Minuses  
   - Using only one of the hydraulic cylinders is marginally sufficient to raise the mast;
   - Using only one hydraulic cylinder defeats the benefits of lateral support intended with the two cylinder design;
   - Using only one hydraulic cylinder removes the safety factor of having a second cylinder back-up;
5) Rebuild the mast to result in a lighter lifting load requirement:

**Pluses**
- Reduces the amount of stress on the support structure;
- Lowers the required hydraulic pressure;

**Minuses**
- Of the total weight lifted, the piping is approximately 16,000 lbs. and the mast approximately 16,000 lbs. Even if the mast could be lightened by 25% (doubtful) the overall result would only be a 12 ½% reduction in total weight;
- If lowering the weight of the existing mast, cutting lightning holes would have a minimal affect;
- If building a new mast from scratch, the process would be costly for a small amount of result;

6) Re-design the lift system such that the base-end connection of the hydraulic cylinder(s) would operate from a point more directly underneath the mast-end connection thus minimizing tension loads in the mast:

**Pluses**
- Provides a more favorable angle to push the mast up resulting in greater vertical force and less horizontal force;

**Minuses**
- Would not be able to use existing hydraulic cylinders;
- New expensive multi-stage cylinder(s) would be required;
- Could possibly result in limited angles of elevation possible;
- Would require a large attachment plate on a relatively thin area of the concrete floor;

7) Add provisions for crane attachment in the event that, whatever lifting system is utilized happened to fail, a crane could be brought in to assist the mast back to horizontal:

**Pluses**
- provides an extra level of safety in the event the hydraulic cylinders become inoperable;

**Minuses**
- None

8) Redesign to allow no more than a limited amount of elevation (example: 30 degrees, 45 degrees):

**Pluses**
- Makes it easier to justify partial solutions;
- Allows for smaller, least expensive components to be used;

**Minuses**
- Goes against the original design premise;

9) Some combination of two or more of the above:

Not applicable for an individual response.