Reasons to integrate controls with system design

I. Guiding principals
1. The control is part of the system. For good system performance, you must design the system to be controlled.
   a. X to RY mechanical coupling has been minimized by aligning the LZMP to the Actuation Plane, UZMP aligned with neutral axis of the spring.
   b. Principle axes of inertia aligned with desired control system
2. Feedback control is not magic, it will not compensate for sub-optimal system designs. It has fundamental limitations of stability, information, actuator strength, and noise. These limitations restrict the performance of all feedback designs.
3. A design that permits simple and robust control designs will be faster, cheaper, and easier to commission, and it will achieve better performance.

II. List of reasons
1. Decoupled mechanical dynamics into separate degrees of freedom (DOFs)
   a. These DOFs should be aligned with a relevant coordinate system, such as parallel and perpendicular to the interferometer (IFO) axis.
   b. Each DOF is controllable with simple SISO control. MIMO is difficult to understand, model, and tune. It may also be less robust. Thus, a system that requires MIMO from the beginning is less likely to perform as well.
   c. Control design effort can be focused on those DOFs that require the best performance.
   d. Lesson learned from quadruple suspension: the principal axes of 'pitch' rotation in 2 of the stages are rotated 10 degrees from IFO coordinate system. This causes large coupling between the 'pitch' and 'roll' dynamics. Not only does this make feedback stability more challenging, but more control loops need high performance tuning because they are sensed by the IFO.
2. Strategic sensor and actuator locations
   a. Observability and controllability, i.e. sensors and actuators have access to relevant dynamics. Can't control what you can't see or drive.
   b. Device noise can limit where they can go, e.g. inertial sensors are useless on the quadruple suspension because the suspension is quieter than any reasonable sensor.
   c. Hierarchy may be needed – big noisy control signals for large displacements, small quiet signals for small displacements. The mechanical design must reflect which of these signals go where. Thus, some idea of the control is needed when the mechanics are designed.
   d. Co-located sensors an actuators (no phase loss between sensor and actuator), Good structural attachment of sensors and actuators

3. Relevant dynamics couple to the control system (if you don't have great sensors or actuators, change the dynamics of the suspension so desired control modes are visible)
    a. Modes that require control are observable/controllable to control system.
    b. Example: suspension modes couple to the top mass so they can be damped where sensor noise is less of an issue.
4. Avoid parasitic vibrational modes
    a. Use a stiff design to push mode frequencies far out of the control band. Low frequency modes limit control bandwidth and stability.
    b. Use passive damping to limit Qs, e.g. Viton.
    c. Mode shapes designed to be invisible to sensors/actuators
5. Big separation of fundamental modes and rigid body modes provides a region to roll off control authority
6. Be conscious payload actuation interactions with the seismic system
7. Control system doesn't need to be robust against fast payload actuation (think fast, hardware protection shutters), one just needs to be able to recover performance quickly.

Open Questions:
1. Do you need to control every degree of freedom?
2. Eddy current damping – a blessing or a curse?
3. Super attenuators are designed to meet ET requirements. If you're limited by infrastructure – can you just take out a few stages?