

SIMPLIFYING DESIGN: Elegance and Economy

by James A. Besho and Stephen F. Burke

Developing simplified solutions to design problems is the hallmark of good project economics during construction and, more importantly, over the long-term operating life of a project, say authors James A. Besho and Stephen F. Burke. Engineers can use both some very old techniques — and some state of the art ones — to achieve optimum simplicity.

A hydroelectric development scheme may have as the developing entity an industrial company, a private entrepreneur, a municipality or a combination thereof. It may have financing from an insurance company, a commercial bank, or municipal bonds; it may be constructed by in-house labor, by a manufacturer of equipment, by a specialty contractor or through sweat equity. The *unique* common element, under any such configuration, is the engineering necessary to give birth to the development concept.

Engineering encompasses not only the pragmatic aspects of harnessing technologies to tap a water resource, but also the insight that can visualize an environment which complements the natural environment while yielding useful benefits.

Keeping It Simple

Some aspects of what engineers do to affect a design (and the ultimate economics) of a hydro project must be understood as art. While this idea will seem heretical at first, consider the definition of art.

Webster's defines art as, "the modification of things by human skill, to answer the purpose intended." No amount of mathematical manipulation of variables will produce a hydro design that completely answers the purpose intended unless some art is present. The engineer builds on the intuitive, insightful concept with the logic of science to achieve practical results.

The notion that technical systems must be inherently complex, to allow for optimization or to achieve best fit, has been ingrained in many of us. In some cases, this overcomplicating of physical systems has resulted from the engineer's inability to analyze, beyond a doubt, certain elements of the design. Hence, a more complex system is formulated to hedge against uncertainty

due to lack of analysis. In some cases, a complex system results from the division of tasks and problems among the design team without an adequate reintegration of the individual component solutions. Each solution may be a best fit for its respective problem, but taken collectively they contradict each other. Fixes are then appended to the project to smooth over the lack of integration between the various design elements. Such an approach is extremely costly.

The best and most *economical* of engineering designs have always been simple but elegant in their execution — from the Roebling bridges to a simple



FIGURE 1: Cylindrical powerhouse solved structural, hydraulic and construction problems.

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piece of silicon engraved to make electrons move logically.

The examples of simple but elegant design in small hydro, while perhaps more mundane, are no less significant to the developer trying to bring a project to fruition:

- Powerhouse designs that minimize hydraulic losses while also minimizing concrete requirements.
- Prefabricated powerhouses which are floated to the site.
- Microprocessor-based control systems that optimize machine performance in real time.
- Turbine designs that allow rapid field alignment.
- Civil designs that respond to conflicting site constraints and compressed construction schedules.

Examples like these are testament to how the engineer can maximize the energy conversion process, while minimizing the capital requirements, and assuring long, productive operating lives of each hydro system.

Reinventing the Wheel

There are few other industries in which most of the basic technology and science is firmly founded in the last century and the first part of this century. More hydro capacity was built before 1925 than has been built since 1975. Unfortunately, the “grey beards” who were present at the birth of hydro energy development are now gone. Their successes remain, but usually only those successes that have withstood the economic ravages of cheap energy. Their early failures and successes are not readily available for this newest generation of energy engineers to learn from. Notwithstanding this lack of first person insight, some operating examples of the original art and science of hydro engineering do remain. In addition, we have vast written resources available. Much of this material predates 1940.

As an example, if you research the pragmatic aspects of induction generation self-excitation, you will find perhaps six technical papers written between 1970 and 1980. Most of this material is highly original work, but it is extremely esoteric. However, you will find 50 or more papers on this topic dating before 1920 — all of which are relevant to the problems presented



FIGURE 2: Precast labyrinth dam answered several hydraulic and scheduling problems.

today by small induction-based hydro generation systems. More importantly, descriptions of failures are more prevalent in earlier, “less sophisticated” technical papers. We are not advocating a return to cylinder cased, camel-back Francis units, but clearly articles about trash rack icing and similar design/operating problems are not necessary, given the abundant empirical data and solid designs available to today’s hydro engineers.

The corollary to past engineering practice being relevant to today’s good

economic design is a need to be aware of the future. Certain technologies, such as microelectronics, are spawning relevant products faster than they can be absorbed by the practicing professional. Staying current in this area is a relative term. In the span of a normal one-year design, procurement, and installation cycle, the technology can change dramatically. It is the engineer’s task to be aware of such new technologies while being mindful of the “older science.” Such integration is an aspect of the art of the entire process.



FIGURE 3: Underground powerhouse responded to a set of environmental constraints and hydraulic problems.

Iteration and Tools

Elegant design — a system or plan that has its apparent parts so melded that they work as a whole — is synonymous with economical design. An elegant design usually has a low number of individual elements, each of which may have several complementary purposes. For example, the upstream face of a cylindrical powerhouse resists the hydrostatic forces through its arch design, while it simultaneously serves to enclose the greatest amount of area within a given perimeter.

The path to achieving such integration and inherent economies of functional requirements is usually an intuitive one. While the concept may occur after some prolonged “sitting on the dam,” reflecting on the project particulars, the detailed synthesis of function and solution that makes for economically superior design requires the science of engineering to quantify,

ascertain, weigh, assign probability and equate. The tools now available to assist in this process did not exist 20 years ago. Accessible computational power and the use of that computational ability in the iterative design

process assures that once an elegant design is conceptualized, it can also be optimized.

The tremendous power of computational tools to simulate and predict the long-term operations of hydro facilities

Simple Goals For Hydro Design Engineers

- Minimize the number of design elements.
- Integrate all elements of civil and mechanical design.
- Strive for hydraulic simplicity, hence efficiency.
- Perform extensive hydrologic risk assessment.
- Keep construction sequencing independent of season.
- Involve all contractors and vendors from the project inception.
- Address environmental issues definitively.
- Provide for operation and maintenance requirements from the onset of design.

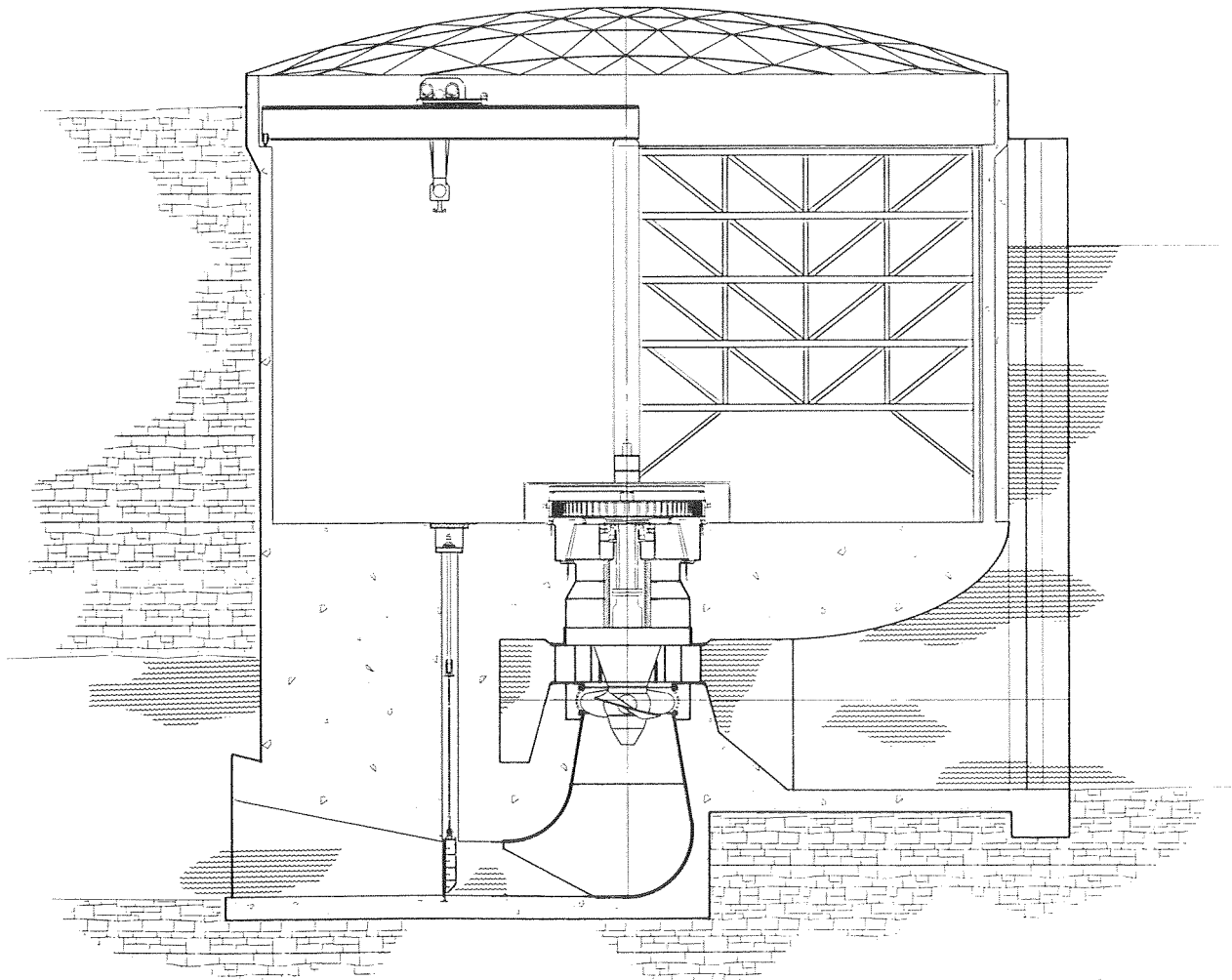


FIGURE 4: Arch design of powerhouse serves as combined equipment enclosure and dam.

can quantify and properly reduce the risk inherent in any long-term capital venture.

The ease and speed of sophisticated numerical analysis allows innovative design concepts to be executed within the confines of conservative and prudent engineering practice and remain economically attractive. Where 10 years ago, perhaps 10 percent of the normal analysis effort completed by the energy engineer was computer based, now 80 to 90 percent is routinely performed using this tool.

The thread that connects the engineer with the physical reality of the project is no longer only the design documents, but may include such elements as computer models that simulate the proposed system. These models are then transferred to the prototype project to operate and optimize the hydroelectric facility in real time.

Paradoxically, the design of a facility can now be kept simple through the use of complex analyses that allow unnecessary redundancy and "over-design" to be minimized.

The Long Haul

Time, as the judge and jury of small hydro, will decide the long-term operating performance of hydroelectric generating facilities. The wave of enthusiasm that met small hydro and other alternative energy schemes in the mid-1970s has subsided into a less dramatic but more forceful tide moving these energy projects forward. The political cheerleaders of small hydro are less visible now, but more knowledgeable. Financial institutions that once considered small hydro very risky now recognize the opportunities and rewards that small hydro can afford.

As the industry has continued to mature, it has realized that a small hydro project is not complete when it goes on line. The engineering proves itself not when the financial tombstone reaches print, but when the debt is repaid and the returns on equity are made.

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