Sustainability principles and practice for engineers

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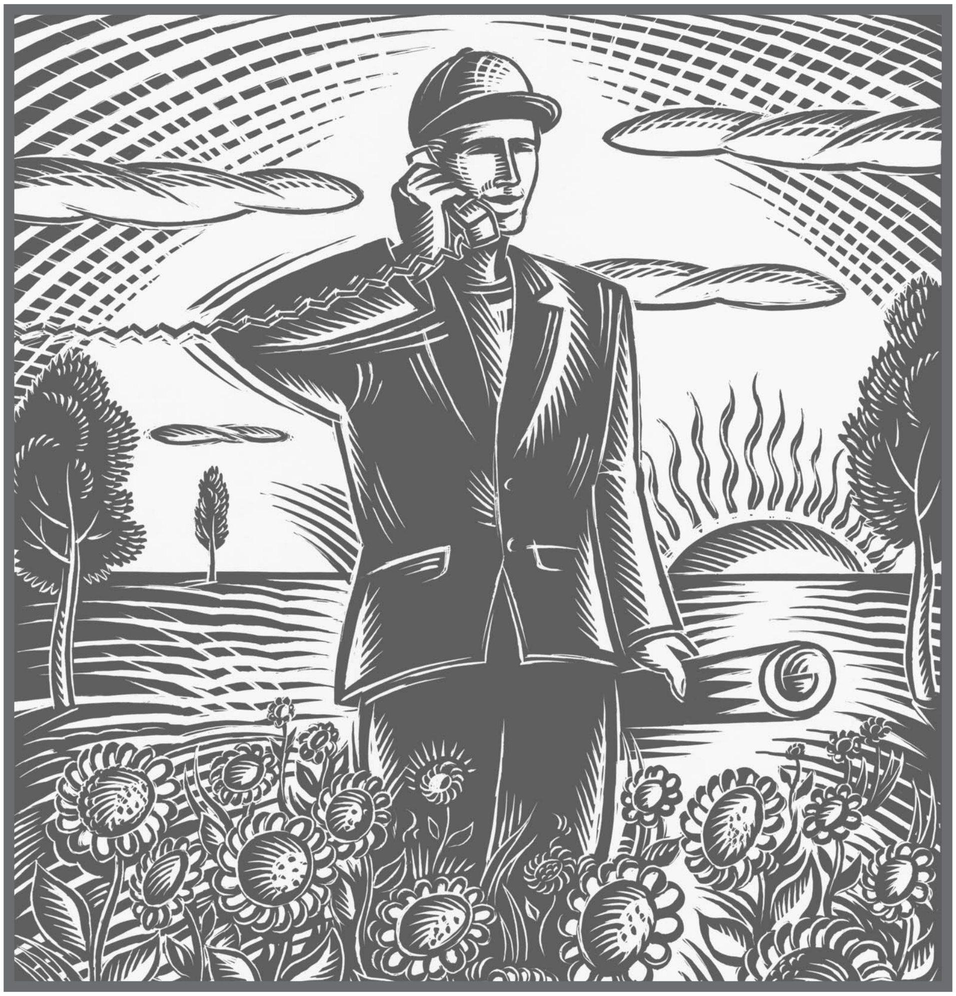

Sustainability Principles and Practice for Engineers

CAROL BOYLE AND GERRY TE KAPA COATES

The Institute of Professional Engineers of New Zealand (IPENZ) Presidential Task Force on Sustainability and Engineering was convened in 2003 by then-President Gerry Coates to "raise the consciousness of engineers in terms of applying sustainability principles in their daily work and thinking." The Task Force recognized that there was little direction for practical application of sustainability to engineering practice, and developed a context and vision for that application. By accepting that existing cities should be thriving over the next 1000 years and that there will be a need for resources and systems for that future, the long-term context of sustainability was brought into focus. A set of sustainability principles for engineers was then developed, based on the long term viability of the planet, intra- and inter-generational equity, and a holistic view for projects and engineering practice –integrating environmental, social, and economic issues. Practical tasks and requirements for engineers, including a checklist were then drawn up to provide further direction to practicing engineers.

Task Force

As part of his year as President of IPENZ, Gerry Coates convened a Presidential Task Force on Sustainability and Engineering. The Task Force members comprised (in alphabetical order) Dr. Carol Boyle, Chair of the NZ Society for Sustainability Engineering and Science and Deputy Director of the International Center for Sustainability Engineering and Research at the University of Auckland; Kathy Garden, Strategic Development Director, Manukau City Council; Andrew McBeth, Consulting Engineer (transportation); Ian Shearer, Consulting Engineering (energy); and Nadine Wakim, Consulting Engineering (environment). All Task Force members had a strong interest in sustainability and its application to engineering and their discipline.

The purpose of the Task Force was to "*raise the consciousness of engineers in terms of applying sustainability principles in their daily work and thinking.*" One of the first tasks to accomplish this was to review the current literature and determine the accepted sustainability principles relevant to professional engineers' roles. It also became clear that an underlying context of sustainability was required to provide a vision of sustainability for engineers. In addition, discussion documents were needed on how engineers should put the principles into practice, as professional engineers but also as engineers working in specialized disciplines.

This article discusses the results of this Task Force, including the underlying context that was developed, the sustainability principles and the discussion on practice for engineers. The Task Force results are available on the IPENZ website [19] and elsewhere [4].

Vision of Sustainability

In 1997, the World Federation of Engineering Organisations (WFEO) issued the following resolution:

> WFEO encourages all engineers to:
> 1) Become knowledgeable of sustainable development principles and be continuously trained about the current sustainable development technologies applicable to their work [29].

Policies, principles, indicators and guidelines for putting sustainability into engineering practice have been developed by the International Federation of Consulting Engineers [12], [13], American Society for Civil Engineers [1], the Institute of Chemical Engineers [14], [15], the Institution of Civil Engineers in the U.K. [16], [17], the Institution of Engineers of Australia [18], and the Association of Professional Engineers and Geoscientists of British Columbia [2].

In addition, there has been much discussion in the current literature of sustainability and its relationship to engineering principles and practice. Overall, there is agreement that traditional engineering solutions and ways of thinking will not produce sustainable solutions [5], [10]; rather such solutions will come from innovation, focuses building on social, cultural and environmental strengths [6], [22], and using lateral or critical thinking [25]. The complexity of interactions that must be considered in addressing sustainability requires a systems thinking approach [20]. However, the thinking required goes beyond understanding and incorporating the relationships of the interacting systems as is addressed in systems thinking; it requires an understanding of change over time, which Emblemsvåg and Bras [8] define as a process thinking approach.

However, the major problem encountered in the application of sustainability to professional practice is that the vision of sustainability and its practical application are unclear. While there are a number of tools that purport to measure sustainability (life cycle assessment, triple bottom line, sustainability impact assessment, Natural Step, sustainability indicators), none of these actually provide a clear measure of sustainability and how future generations are to be taken into account [7], [9], [11], [20], [21], [24], [27]. Most merely assess progress towards sustainability, without defining what sustainability is and therefore the progress proceeds blindly. Some means of putting sustainability into context was needed to be able to provide engineers with a focus.

The basic concept of sustainability as stated in "Our Common Future" [28] requires a focus on intra- and inter-generational equity (ensuring that the needs of the current generation are met without compromising the needs of future generations). This is a common theme for most definitions of sustainability. A U.K. government definition of "ensuring quality of life" focuses only on the social aspect of sustainability and does not consider if there are sufficient resources to achieve the quality expected by individuals [7]. In putting the concept of future generations into practice though, there is no clear understanding of what is meant by future generations. Economists argue that we care about our children, their children and possibly their children, but beyond four generations we do not have a sense of concern or obligation for future welfare. Some indigenous peoples, such as New Zealand Maori, would identify five generations as the minimum period of thinking.

However, in the context of future society, four or five generations (100-125 years) is relatively short. Many societies have existed for much longer than that – some for thousands of years (Europe, Middle East, China, India, Egypt). Most of the major cities in Europe, north Africa, the middle East, and Asia have been in existence for over one thousand and many for two thousand years; some for over 5000 years. Some environmental impacts can last for thousands of years, particularly loss or salinization of soil, loss of resources, degradation of ecosystems, and loss of biodiversity. Some impacts can take long periods of time to develop or occur – loss of soil or biodiversity, desertification, deforestation, and depletion of resources. Thus, at the very least, we should be considering a period of 1000 years and looking to the type of future we want at that point. As Tonn [26] points out, this concept is being recognized and needs to be incorporated into current urban and regional planning; Boyle [3] also suggests that sustainability should be measured using risk over a thousand years.

We cannot, of course, know what technologies we will have available 1000 years into the future. However, we can make some assumptions and use these to guide sustainable thinking. These assumptions include:

a) humans will be here; current cities will be here;
b) food will still be grown;
c) materials and energy will still be required to meet human needs;
d) human basic needs will not have changed;
e) these include [23]:

- Existence – provision of the basic biological needs of its members: food, drink, shelter, and medical care;
- Effectiveness – provision for the production and distribution of goods and services;
- Freedom of action;
- Security - provision for the maintenance of internal and external order;
- Adaptability – ability to change;
- Coexistence – ability to exist peacefully with other races and species;
- Reproduction - provision for the reproduction of new members and consideration of laws and issues related to reproduction;
- Psychological needs – provision of meaning and motivation to individuals;
- Ethical reference – provision of definitions of right and wrong.

Long-Term Planning

On this basis, we can then determine what we have to consider over 1000 years. Land use, food production, soil health, water quality and quantity, human habitation, ecosystem health, evolution and robustness, biodiversity, waste disposal (particularly hazardous waste), climate change, resource use, and even technological direction are all suitable for long term consideration. Once we have started to plan for these factors, we set the framework for our future direction and how we can enable future generations to meet their needs. Long term planning for cities, regions, and countries becomes important as it is within that framework that infrastructure of human habitation can be developed and managed for the long term. Limitations of land, water, food, soil, and materials can be identified and ways of managing those resources within those limitations developed. Areas that are suitable for human habitation, for agriculture, for transportation corridors and for green areas can be identified and managed. Solutions, including new technologies that must be developed for future survival, can then be identified through backcasting. Backcasting identifies the solutions that are needed and then determines the pathways that must be followed to obtain those solutions.

Having identified these issues, we certainly cannot predict with any certainty what will happen in the future. However, we can evaluate the risk of our activities on the needs of future generations and reduce those risks. Thus we can look at the probability and consequences of negative impacts on the environment and society over the short, medium, and long term and move to mitigate those risks, particularly those that have major consequences. This will require a combination of not only changing existing practices, but also focusing research in directions that will lead towards sustainability.

The identification of risks requires that we understand more fully the systems we are affecting – environmental and social, including economic. Systems thinking is critical to enable the linkages and feedbacks between systems to be identified and for planning to take all systems into account. It also requires us to identify and recognize the limitations of those systems, not only for the short term but also for the long term. Those are the limitations that we must live within if we are to achieve sustainability. At this point, we have identified some critical ecosystem levels and species, the points at which ecosystems will crash. However, the causes and factors leading to such crashes are not well known and the critical levels of many species and ecosystems remain unknown.

The implications of sustainability for engineers are major. Long term thinking on resource availability and infrastructure planning is essential. Paradigm shifts in economics and technology design are necessary. Clearer and better understanding of how to provide for a good quality of life without necessarily increasing the quantity of goods is required. Individual responsibility for the future also needs to be clarified and accepted.

Needs vs. Wants

Engineers, in collaboration with politicians, planners, social scientists, and other professionals, need to become more effective at identifying the needs of consumers and clients, rather than "wants," particularly the need for technology. This will require engineers to become problem framers by asking the client to identify the core of the problem, rather than just the solution. It will also mean deciding on the most effective directions that technology takes, rather than relying solely on market drivers. Overall, engineers need to be aware of the potential long-term impacts of their actions rather than merely using a predict and provide model.

Plato, writing *Critias* 2400 years ago [30], lamented the impact of deforestation and farming on the Greek island of Attica:

> *...all other lands were surpassed by ours in goodness of soil, so that it was actually able at that period to support a large host which was exempt from the labors of husbandry. And of its goodness a strong proof is this: what is now left of our soil rivals any other in being all-productive and abundant in crops and rich in pasturage for all kinds of cattle and at that period, in addition to their fine quality it produced these things in vast quantity... And, just as happens in small islands, what now remains compared with what then existed is like the skeleton of a sick man, all the fat and soft earth having wasted away, and only the bare framework of the land being left. But at that epoch the country was unimpaired, and for its mountains it had high arable hills, and in place of the "moorlands," as they are now called, it contained plains full of rich soil; and it had much forestland in its mountains, of which there are visible signs even to this day; for there are some mountains which now have nothing but food for bees, but they had trees no very long time ago, and the rafters from those felled there to roof the largest buildings are still sound. And besides, there were many lofty trees of cultivated species; and it produced boundless pasturage for flocks. Moreover, it was enriched by the yearly rains from Zeus, which were not lost to it, as now, by flowing from the bare land into the sea; but the soil it had was deep, and therein it received the water, storing it up in the retentive loamy soil and by drawing off into the hollows from the heights the water that was there absorbed, it provided all the various districts with abundant supplies of springwaters and streams, whereof the shrines which still remain even now, at the spots where the fountains formerly existed, are signs which testify that our present description of the land is true.*

Developing Principles for Engineers

It was recognized by the Task Force that for engineers, sustainability principles had to bridge the gap between existing practice and the long-term focus on sustainability. They also had to take the integrated, holistic view of environment, society, and economics into account. Above all, the ongoing viability of the natural environment had to be maintained. From this the following principles were developed.

Sustainability Principles for Engineers

Sustainability is the focus on the long-term survival of humanity, with the recognition that decisions made today need to enable both those in the present and in the future to make effective choices about their quality of life. Three key principles are the basis of sustainability, to provide future generations with choices and with a direction that will enable long-term survival of humanity.

Principle 1: Maintaining the viability of the planet

a) Humans need to maintain the integrity of global and local biophysical systems to retain the irreplaceable life support functions upon which human well-being depends.

b) The efficiency of products needs to be improved and the material and energy intensity needs to be reduced by a factor of 10 to 50 to achieve sustainability; thus redesigning engineered products, processes, and services and minimization, recycling, and reuse of resources are needed to achieve this factor.

c) Depletion rates of non-renewable resources shall equal the rate at which renewable substitutes are developed by human invention and investment.

Renewable resources must be managed to ensure that they can be produced over the long term without damage to the environment, and harvest rates of renewable resource inputs must not exceed the regenerative capacity of the natural system that generates them.

d) All waste products from the life cycle of engineered products, processes or systems should be eliminated, preferably at the source. Waste discharge should be kept within the assimilative capacity of the local and global environments.

e) The use of hazardous materials must be minimized and, wherever possible, eliminated.

f) The use of materials and chemicals that can accumulate in the environment needs to be reduced to a minimum that will not exceed natural or hazardous levels, whichever is lower.

g) When selecting an engineering option for product design, processing or providing a service, weight shall be given to choices that, for a given expenditure, minimize the use of resources, particularly non-renewable resources such as fossil fuel-based energy and metals.

h) Options chosen for product design, processing, or providing a service should be based on the precautionary principle and reduce risk as much as practicable or foreseeable.

Principle 2: Providing for equity within and between generations

i) All members of society have equal rights to achieve an acceptable quality of life, to be given choices in their life and to work to reduce significant gaps in health, security, social recognition, political influence, etc. between rich and poor people. These rights must be respected.

j) Excessive consumption of resources by the wealthy needs to be reduced to allow those in poverty to fulfil their needs while ensuring resource use is within the environment's carrying capacity.

k) Development and resource use must be considered over a sufficiently long time scale so that future generations are not disadvantaged economically, socially, or environmentally.

l) All those affected by engineering projects need to be given equal opportunity without repercussions to voice their concerns and opinions and to have their views incorporated into the planning and decision making process.

Principle 3: Solving problems holistically

m) Problem solutions shall be based primarily on human needs and ecosystem viability rather than the availability of technology.

n) A holistic, systems-based approach shall be used to solve problems rather than focussing on technology alone.

o) Methods that provide optimum outcomes for all stakeholders rather than expedient or single solutions shall be implemented.

p) The use of non-sustainable practices or practices that present a risk to sustainability shall be minimised and reduced to zero over time. Where it is practicable or desirable, past degradation must be reversed.

q) Problem solving shall be based on prudent approaches and not through solving one problem at the expense of another.

Putting the Principles into Practice

The principles, as developed, provide engineers with a framework but require more detail for engineers as to how to put them into practice. An overview of sustainability and engineering practices was prepared by the Task Force, outlining practical tasks and requirements for engineers from all disciplines and sectors.

Sustainability & Engineering Practices Overview

This overview translates sustainability principles into overarching practical tasks and requirements for the engineering profession as a whole. These also apply to a greater or lesser extent to all sectors.

Because sustainability has a long-term focus, beyond the life of most engineering projects, products, processes, or systems - generically called projects - the methodology and resource use by projects needs to focus on both short- and long-term factors. This is often far beyond the duties imposed by professional codes of ethics.

Key sustainability factors for engineers are:

- The need to **manage changes in the environment** (both local and global) as the consequence of any engineering activities to ensure the continued viability of the planet (Principle 1).
- Ensuring the **equity and safety of engineering activities** for both current and future generations is also of high importance (Principle 2). Wherever possible this also means **improving the quality of life**, particularly for the poor and those in developing countries.
- **Problem solving**, one of the key aspects of a professional engineer's skills, needs to be done in a holistic way (Principle 3), so that solving one problem does not create another, and the solution arrived at is the optimum one from many viewpoints.
- Where practicable engineers need to consider **resolving existing problems** caused by failures to follow sustainability principles (Principle 3).

These factors are explored further below, from an engineering perspective.

Key Sustainability Factors

Managing changes in the environment

1) Maintain the integrity of global and local biophysical systems. Engineers must thoroughly consider any project or plan that will have a significant impact on the life support functions upon which human well-being depends, many of which are irreplaceable. For example the use and placement of dams on waterways, or the deployment of a technique, material or process with unknown side effects - such as nanotechnology assembly processes.
2) Ensure that the true cost of resource depletion is included in all feasibility studies and estimates. Usually the market cost is assumed to include all costs, but this is often not so, and where alternatives exist, the more sustainable product or material should be used. For example a recyclable or reusable container is inherently more sustainable than a single-use container, whatever the apparent cost.
3) Minimize the absolute use of resources, and convert the energy source from fossil based to renewable energy. This requires a constant awareness of optimization processes on a life cycle basis, for example engineered products, processes and services should be designed to minimise the initial use of resources and to provide for maximum recycling and reuse of resources. This applies both to scarce resources, and apparently abundant resources such as concrete and timber, all of which have an embedded energy content.
4) Maximize the use of renewable resources but always within sustainable extraction or harvest rates and taking account of environmental damage. For example biomass from sustainable forests can be used as a boiler fuel instead of oil or gas.
5) Minimize waste products, particularly hazardous ones, from the total life cycle of engineered products, processes or systems, preferably as near to the source as practicable: Ensure that any waste discharges are within the short term assimilative capacity of the environment, without long term accumulation.

Equity and safety of engineering activities

6) Engineering projects, products or processes should be aimed primarily at improving the overall quality of life for humans and other life forms, but not at the expense of the environment.
7) Any increased consumption of resources and energy, must be weighed against the improvement in quality of life to be achieved.
8) Resource use must be considered over a sufficiently long time scale so that present and future generations are not disadvantaged economically, socially or environmentally, by excessive and unnecessary consumption. This may be considerably longer than an anticipated project lifetime.
9) Positively weight projects, products and processes that decrease significant gaps in health, security, social recognition, and political influence between groups of people. Those that do the opposite should be carefully considered before embarking on them in whole or in part.
10) All those affected by engineering projects shall be consulted where practicable and given equal opportunity without repercussions to voice their concerns. Their relevant opinions shall be considered and where practical incorporated into the planning, decision making and implementation process.
11) Where outcomes cannot be accurately foreseen choices shall be based on risk reduction and the precautionary principle - where in the absence of data, new risk is avoided - as much as practicable or foreseeable.

Holistic problem solving

12) An integrated systems, or an overall holistic, approach shall be taken including all stakeholders and the environment when attempting to solve problems. Rather than focusing solely on the technology aspects, and solving one problem at the expense of another, a coordinated solution shall be the aim.
13) Problem solutions shall be based primarily on existing or new human needs rather than finding a use for a newly available technology or technological method.
14) Approaches that are multifaceted, and synergistic are preferable to single issue approaches. For example, using transportation in such a way that viable loads are available for both journeys is more sustainable than single load journeys.

Resolving existing problems

15) Where desirable and technically and economically practicable, past environmental degradation should be remedied. For example, land degradation, groundwater contamination, and hazardous waste sites should be, at a minimum, stabilized, and wherever possible remediated, to current or foreseeable standards.

16) Past hazardous practices shall cease and hazards shall be cleaned up in a cost effective way and time frame. These include, for example, hazardous materials such as asbestos, lead, mercury, and PCBs.

17) Reduce the use of non-sustainable practices (such as burning or using petroleum and fossil fuel products for feedstocks) to zero over a relatively short time frame.

18) Support social and economic accounting methods which disclose, identify and quantify previous or developing environmental problems.

1. Have you thoroughly considered any project or plan that will have a significant impact on the life support functions upon which human well-being depends? ☐
2. Have you ensured that the true cost of resource depletion is included in all your feasibility studies and estimates? ☐
3. Have you minimized the absolute use of resources on a life cycle basis, and used renewable energy as much as possible? ☐
4. Have you maximized the use of renewable resources within sustainable extraction or harvest rates and taken account of environmental damage? ☐
5. Can you minimize waste products, particularly hazardous ones, from the total life cycle of engineered products, processes or systems, as near to the source as practicable? ☐
6. Does the project, product, or process improve the overall quality of life for humans and other life forms, without large increases in the consumption of resources and energy, or at the expense of the environment? ☐
7. Has resource use been considered over a sufficiently long time scale so that present and future generations are not disadvantaged by excessive and unnecessary consumption? ☐
8. Does the project, product, or process decrease comparative gaps in health, security, social recognition, political influence between groups of people as much as it could? ☐
9. Have those likely to be affected by the project been consulted if practicable, and will any relevant opinions be considered and where practical incorporated into final planning? ☐
10. If outcomes cannot be accurately foreseen, is your planning based on risk reduction and the precautionary principle? ☐
11. Have you taken an integrated systems, overall holistic approach including all stakeholders and the environment in your proposed solution? ☐
12. Is your project, product or process based on human needs rather than just finding a use for some newly available technology? ☐
13. Does the project, product or process involve past hazardous practices, and if so can these be eliminated and cleaned up in a cost effective way and time frame? ☐
14. Does the project, product or process contribute towards reducing non-sustainable practices to zero over a relatively short time frame? ☐
15. Can social and economic accounting methods be used at the planning stages to disclose, identify and quantify previous or developing environmental problems? ☐

Fig. 1: General sustainable engineering and technology checklist.

Implications for IPENZ Members and Engineers in General

A policy framework is emerging in New Zealand for sustainable development to be implemented in certain specific areas. Engineers have many opportunities to be involved in this process. They also have professional responsibilities to do so, as noted, for example, in the IPENZ Code of Ethics:

> "Members shall be committed to the need for sustainable management of the planet's resources and seek to minimise adverse environmental impacts of their engineering works or applications of technology for both present and future generations."

Members of IPENZ and of its various technical groups and societies are encouraged to learn more about sustainability and apply it in their day-to-day actions at work and in other aspects of their lives. Further information is readily available both from New Zealand and internationally. The engineering profession should lead the way and be seen to lead the way towards a more sustainable future.

There a number of specific ways in which engineers and the engineering community can move New Zealand towards sustainability. The checklist shown in Fig. 1 gives some guidance on this.

It needs to be recognized that existing practice and reality conflict strongly with many of the points raised in the checklist. Much of this is due to the perceived role of engineers as being a "servant" to a client, rather than an expert, and relates back to the role of engineers as technicians rather than professionals. In addition, there is the traditional, conservative approach favored by many practicing engineers, not only to reduce liability but also because it is the easy approach. Much work is necessary by engineers to realize their role as professionals and to live up to that role through educating and advising clients.

Requiring Sustainability in Engineering Practice

There has been much discourse on the topic of sustainability and its application to engineering practice. Most professional engineering associations have incorporated a requirement for engineers to include sustainability in their practice but there has been little work done on how this can be successfully achieved. Based on an underlying vision of cities thriving for 1000 years, the long-term focus of sustainability becomes a reality as resources and systems must be able to provide for that future. From this, sustainability principles for engineers were then developed, focused on the long-term viability of the planet, intra- and inter-generational equity and a holistic view for projects, integrating environmental, social and economic issues. Practical tasks and requirements for engineers, including a checklist, were then drawn up to provide further direction to practicing engineers.

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