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The Responsibilities of Engineers

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Abstract Knowledge of the responsibilities of engineers is the foundation for answering ethical questions about the work of engineers. This paper defines the responsibilities of engineers by considering what constitutes the nature of engineering as a particular form of activity. Specifically, this paper focuses on the ethical responsibilities of engineers *qua* engineers. Such responsibilities refer to the duties acquired in virtue of being a member of a group. We examine the practice of engineering, drawing on the idea of practices developed by philosopher Alasdair MacIntyre, and show how the idea of a practice is important for identifying and justifying the responsibilities of engineers. To demonstrate the contribution that knowledge of the responsibilities of engineers makes to engineering ethics, a case study from structural engineering is discussed. The discussion of the failure of the Sleipner A Platform off the coast of Norway in 1991 demonstrates how the responsibilities of engineers can be derived from knowledge of the nature of engineering and its context.

Keywords Responsibility · Sleipner A Platform · Standards · MacIntyre · Tradition

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Introduction

Knowledge of the responsibilities of engineers is key to answering ethical questions about the work of engineers. The decisions made by engineers often have ethical dimensions and implications. Engineers develop and implement technologies that influence and shape the way we live, at times in unanticipated ways (van der Burg and van Gorp 2005; Wetmore 2008). Engineering projects are also likely to influence large populations (Wenk 1989). In addition, engineers impact society by maintaining positions in industry and academia that influence public policy (Layton 1971; Mead 1980; Unger 1994; Badaracco and Webb 1995; Nissenbaum 2002; Pielke 2007). These roles carry unique ethical challenges. To be able to answer important ethical questions, it is essential first to define what the responsibilities of engineers are.

Current literature recognizes a number of challenges in defining engineers' responsibilities. Deborah Johnson argues that applied moral theories have yet to reveal what social responsibilities engineers have specifically as engineers (Johnson 1992). Similarly, other authors have recognized various problems in the use of maxims from moral philosophy as guides to defining the responsibilities of engineers (Busby and Coeckelbergh 2003; Bowen 2010). Neelke Doorn and Michael Davis have introduced philosophical models of responsibility to engineering ethics; however, they are not intended to identify what engineers' responsibilities are (Doorn 2009; Davis 2010). Instead they describe the practical benefits that come from a better understanding of responsibility and provide frameworks for determining ethical courses of action. Finally, it is common to emphasize those responsibilities expected of professionals in general when discussing the responsibilities of engineers. This is how Charles Fleddermann grounds the responsibilities to protect client confidentiality and to avoid conflicts of interest (Fleddermann 1999). All of these approaches, however, do not answer the fundamental question of what responsibilities engineers have *qua* engineers.

The paper proposes a formal list of the responsibilities of engineers. After providing more detailed background on the subject of responsibility in the next section, the paper lays out the concepts that the moral philosopher Alasdair MacIntyre has used to explain practices. The responsibilities of engineers are then defined by considering what constitutes the nature of engineering as a particular form of activity or practice (MacIntyre 1984a, b). Finally, a case study of the failure of the Sleipner A Platform off the coast of Norway in 1991 is discussed which deals with responsibilities in the discipline of structural engineering.

Background

This section first reviews the literature on engineers' responsibilities. Then, we provide the definition of responsibility adopted in this paper and discuss how this definition contributes to the goal of identifying the responsibilities of engineers.

Responsibility itself is a complex subject. In moral philosophy and engineering ethics, the term responsibility has varying meanings and qualifications. For example, some speak of responsibility as a form of accountability, while others link it with conditions for blameworthiness (Fischer and Tognazzini 2011; Smith 2007; Doorn and Nihlén-Fahlquist 2010; Doorn 2009; Watson 1996; Davis 2010). The requirements to prove an individual is responsible and what they can actually be responsible for are also variable. In moral philosophy distinctions are drawn among various types of responsibility, including causal, legal, moral and professional responsibility. Not all responsibilities are co-extensive. For instance, one can accidentally be causally responsible for an incident, but not held legally responsible.

In the contemporary engineering ethics literature, authors often contrast social and technical responsibilities, and there is disagreement about which kind of responsibility should be prioritized. Carl Mitcham notes that American engineers in the 1960's and 1970's criticized the technocratic movement of previous decades for its lack of social consciousness (Mitcham 1994). Mitcham's observation highlights the difference between thinking that engineers are responsible for technological advancement only, as opposed to being responsible for the consequences that technology has for people. The difference between technical and social responsibilities is also an issue in readings such as Bowen (Bowen 2010, pp. 135–136). Bowen points to two problems with an overemphasis on technical progress. First, he claims that much energy, including economic resources and time, is spent on the development of technologies, such as weaponry, that he argues do not benefit society. Second, Bowen points out that even established engineering technologies, such as water sanitation, are not available to everyone who needs them. Bowen concludes that engineers should work to correct the imbalance between technological ability and social need by prioritizing people. However, it is unclear whether the responsibility should be one belonging directly to engineers or if society should be responsible for resource allocation and support so that engineers can work toward such priorities. Also, it is hardly explicit in any paper that takes up these differences what exactly differentiates technical responsibilities from social responsibilities.

Finally, there is significant debate about the extent to which engineers have the responsibility to contribute to the betterment of society. Some authors base the responsibility to benefit society upon aspirational ethics, appeals to codes of engineering ethics requiring engineers to "hold paramount the safety, health, and welfare of the public," or duties of professionalism (Nichols and Weldon 1997; Bowen 2010; Davis 1997; Harris 2008; Pritchard 1998, 2001; NSPE 2007). There is also a contrary, though less popular, view. James Stieb claims that the responsibilities of engineers ought to be limited to the realm of professional competence, committing engineers only to the responsibility of avoiding harm to others while absolving engineers of the commonly accepted responsibility to benefit humanity (Stieb 2011). As with the difference between the technical and social responsibilities, this disagreement between an obligation to avoid harm or to benefit society in part depends upon where one chooses to draw the line between harmless and beneficial technologies.

In these discussions, accounts of the responsibilities of engineers are often developed by applying moral theories, such as deontology, consequentialism, and virtue ethics, to engineering problems. The differences among moral philosophies are openly acknowledged by a number of authors. Busby and Coeckelbergh, for instance, note that there is a common perception that engineers make ethical decisions based upon utilitarian principles, while the public tends to form their expectations of engineers along deontological lines (Busby and Coeckelbergh 2003). From this latter perspective, engineers see themselves as largely responsible for reducing quantifiable levels of risk and harm, while the public thinks that engineers are responsible for fulfilling strictly prescribed duties to society. Richard Bowen argues that the theories of consequentialism, contractualism, and deontology have specific disadvantages when instituted in the field of engineering ethics (Bowen 2010). Bowen claims that consequentialism contains no provision for justice, contractualism limits ethical aspiration, and deontology's dense philosophical foundation is too impenetrable for engineers.

This paper focuses on the ethical or moral responsibilities of engineers *qua* engineers. Responsibilities "*qua* engineers" refer to the duties acquired in virtue of being a member of a particular group. In this paper, we use the terms "ethical" and "moral" interchangeably. Ethics refers to standards of conduct governing, in Carl Skooglund's words, "how we agree to relate to one another" (in Nichols and Weldon 1997). Thus the ethical responsibilities of engineers *qua* engineers are "those (morally permissible) standards of conduct (rules, principles, or ideals) that apply to members of a group [in this case engineers] simply because they are members of that group" (Davis 2011). More specifically, the responsibilities of engineers captures those duties specified by the standards and methods set for engineering by society and engineers.

In this paper we propose a set of responsibilities for engineers *qua* engineers. Our justification of the list of the responsibilities of engineers draws upon the moral philosophy of Alasdair MacIntyre and the idea that our responsibilities are defined in terms of practices and are socially and historically developed. This justification does not assume at the outset that the ethical responsibilities of engineers *qua* engineers should or should not include technical and/or social duties. It also provides a way of grounding responsibilities that is dependent on utilitarian, contractual or deontological moral theories. Finally, as we show later, a practice-based approach to responsibility provides resources for understanding why the contrast between a narrow responsibility to exercise technical competence avoiding harm versus a broader responsibility to contribute to society is misleading. We argue that exercising technical competence in engineering, properly understood, contributes to technical advancement and the betterment of society.

In the next section we provide an overview of MacIntyre's understanding of practices and traditions. This provides the theoretical background to the positive account of the responsibilities of engineers developed in later sections.

Practices, Standards of Excellence, Goods, and Traditions

The proposed responsibilities of engineers are based on the definitions of practices, standards of excellence, goods and traditions put forward by philosopher Alasdair MacIntyre. This section describes these concepts and how they contribute to the definition of engineers' responsibilities.

Practices

MacIntyre defines a practice as (MacIntyre 1984a, p. 187):

> …any coherent and complex form of socially established cooperative human activity through which goods internal to that form of activity are realized in the course of trying to achieve those standards of excellence which are appropriate to, and partially definitive of, that form of activity, with the result that human powers to achieve excellence, and human conceptions of the ends and goods involved, are systematically extended.

In other words, a practice is a socially organized activity partially defined by standards of excellence unique to that activity. Practices have their own goals such as the achievement of standards of excellence and their own rewards such as goods. As standards of excellence are regularly met and goods of the practice are realized, practitioners find ways to improve upon these elements so that practices evolve.

Practices are important for this line of inquiry into the responsibilities of engineers because the concept of practices gives us a basis for understanding engineering as an activity with its own standards and goods. Responsibilities exclusive to the practice can then be derived from these exclusive elements.

Standards of Excellence and Goods

Standards of excellence are criteria specific to the practice that determine what counts as success for practitioners (MacIntyre 1984a, p. 190). Participants in a practice accept standards of excellence as authoritative. MacIntyre says that "we cannot be initiated into a practice without accepting the authority of the best standards realized so far." (MacIntyre 1984a, p. 190) Practitioners strive to achieve excellence in their practice, as defined by the standards of excellence. As practitioners work to achieve and maintain standards of excellence, the practice evolves and the standards are refined.

It is important to recognize two points about standards of excellence as MacIntyre intends them to be understood. The first is that practices, by definition, evolve and change. So do their standards. Today's standards of excellence represent a historical improvement over past standards and are the foundation for future improvements. Second, not everyone at all times can either achieve the standards of excellence or elevate them. What practitioners do is strive to achieve and surpass them.

Internal goods are specific to a practice and can only be achieved by practitioners participating in that practice and striving to meet the practice's standards of excellence (MacIntyre 1984a, pp. 188–190). Drawing on MacIntyre's own example, consider chess. Internal goods specific to chess include "the achievement of a certain highly particular kind of analytical skill, strategic imagination and competitive intensity" (MacIntyre 1984a, p. 188). Such internal goods serve as reasons for participating in and trying to excel in the practice (MacIntyre 1984a, p. 188). They are also goods only achieved through satisfying the standards of excellence constitutive of a practice, in the case of chess playing the game well.

In MacIntyre's view, internal goods are genuinely good; that is, standards of excellence serve to promote ends or goals that are fundamentally valuable. Activities that do not pursue what can plausibly be construed as valuable ends or goals cannot constitute practices. Consider what MacIntyre says about certain immoral actions which some have suggested are practices:

> …spying, smuggling, the art of the executioner, and torturing […] just do not, so it seems clearly to me, involve systematic extension of our conceptions of the ends and goals which excellence may serve—one central characteristic of practices, understood as I understand them (MacIntyre 1984b).

In other words, there is no internal good genuinely achieved through the activity of torturing.

Internal goods are as numerous and prevalent as are practices, and each practice has its own internal goods. Playing chess, working in engineering, and participating as a citizen in a political community are all practices that are pursued for the sake of different internal goods. Moreover, each individual is part of multiple, simultaneously occurring practices. [1]What is important for engineers, we suggest later, is to understand how the internal goods of engineering compliment the goods of the other practices of which they are a part, such as the practice of being a member of a particular geographic community, and the larger traditions in which their current lives are embedded.

External goods are those goods, such as money and prestige, that are not associated with any particular practice, and can understood or achieved in various ways (MacIntyre 1984a, p. 188). In particular, achieving external goods does not depend on pursuing excellence in a practice or indeed participating in any particular practice.

Mathematics is a practice because it is a field that has its own standards of excellence, which mathematicians regularly attempt to achieve and improve upon. Mathematics has a lively social history marked by the sharing and building up of ideas in university math departments, in journals, and in research. All of this activity is designed to systematically extend the standards for success in the field and the internal goods achieved through the pursuit of such excellence. By contrast, adding numbers is not a practice but merely a technical skill. Mere technical skills do not necessarily serve the pursuit and achievement of any particular goods. By contrast, participating in a practice requires the exercise of technical skills, but such skills exercised for the sake of and directed towards the pursuit of certain internal goods (MacIntyre 1984a, p. 193).

Standards of excellence and internal goods are the foundation from which we derive the responsibilities of engineers. Internal goods are important because they serve as reasons for engaging in the practice. Standards of excellence help determine what level of performance practitioners ought to strive for in their practice. The following is an initial statement about the responsibilities of participants in a practice. First, practitioners are responsible for knowing,

[1] This article focuses mainly on the practice of engineering and its goods while leaving the issue of how these goods fit with other goods that an individual may pursue for later work.

maintaining and improving the standards of excellence of a practice. Third, practitioners are also responsible for engaging in the practice for the right reasons, that is, with an interest in pursuing its internal goods.

Traditions

MacIntyre's concept of tradition encourages us to view the responsibilities of members of a practice, such as engineering, from a historical and broader social perspective.

> MacIntyre defines tradition in the following terms:
> A living tradition then is an historically extended, socially embodied argument, and an argument precisely in part about the goods which constitute the tradition. Within a tradition the pursuit of goods extends through generations sometimes through many generations. Hence the individual's search for his or her good is generally and characteristically conducted within a context defined by those traditions of which the individual's life is a part, and this is true both of those goods which are internal to practices and of the goods of a single life (MacIntyre 1984a, p. 222).

A tradition is a historically extended process of collectively reasoning about what defines the good or goods of a practice or an individual life. What is an internal good today will be influenced by conceptions of goods previously determined by past members of a practice. The history of a practice forms a tradition. In MacIntyre's words, "practices always have histories and that at any given moment what a practice is depends upon a mode of understanding it which has been transmitted often through many generations (MacIntyre 1984a, p. 221)." Understanding the present practice by knowing its history is how a practice becomes intelligible (MacIntyre 1984a, p. 222).

Traditions are important because the tradition of a practice adds context to our understanding of the practice. This fact has several implications for the knowledge of practitioners' responsibilities. First, the tradition of a practice is important because it serves as the origin from which current practitioners learn their standards of excellence and thus responsibilities. As one participates in a practice by achieving and advancing its standards of excellence what defines those standards evolves. As a result, the goals and goods of our practices are extended. Second, when outsiders attempt to understand a practice and the responsibilities of practitioners, the historical context provided by the concept of tradition aids in that understanding. Thus, the knowledge of the tradition is important because it allows us to answer the question whether or not practitioners are making progress in the furthering of their practice.

Responsibilities

In previous sections, we made some initial statements about the responsibility to know, maintain, and advance standards of excellence. In this section, these statements will be organized and expanded upon.

Initially, we said that a practitioner is responsible for three things in relation to the relevant standards of excellence in their practice. The three responsibilities associated with standards of excellence are:

1. Learning the current standards of excellence defining the practice.
2. Maintaining adherence to those standards of excellence as one engages in the practice.
3. Advancing the standards of excellence by identifying and solving problems faced by the practice.

We also said that practitioners ought to engage in their practice for the right reasons, to achieve and advance the internal goods of the practice. This does not mean that external goods are not important. However, achieving the internal goods of the practice by striving to maintain standards of excellence should constrain the pursuit of external goods. This is important because the reasons for deciding one course of action over another, especially when a professional such as an engineer is also a member of an institution or corporation, often conflict. If engineers prioritize financial gain or notoriety above the achievement of objectives such as safety, sustainability, and technical excellence, unethical behavior is more likely to result. Numerous case studies on whistle-blowing have demonstrated the ways that institutional organizations fail to acknowledge the ethical concerns of engineers grounded in their interest in protecting and promoting the internal goods of engineering (Mitcham 1994). This is not surprising given that many institutions, such as corporations, have as their function producing sustainable profit margins and tend to influence engineers into serving the ideals of profitability first, regardless of whether or not the internal goods of engineering are achieved in the process.

We formulate the responsibility associated with engaging in a practice for the right reasons in the following way:

4. Practitioners are responsible for making decision in their work based upon the understanding that the quest for external goods and the power of institutions must be tempered with an emphasis on the internal goods of practices.

MacIntyre’s concept of tradition encourages us to also view responsibility as an obligation that is inherited from past practitioners and passed on in modified form to future practitioners. In the previous section we stated that practitioners do inherit problems, solve them, and formulate new ones to be passed on. This is one way that responsibilities can be derived from the concept of tradition. Two further relevant responsibilities thus are:

5. Practitioners are responsible for working on the problems inherited from the past.
6. Practitioners are responsible for working toward the solution of present and future problems.

The final responsibility that this paper finds important is derived from the fact that our actions and intentions must be understood narratively. Having an accurate account of why a person behaved in a certain way is a precondition for being able to praise or blame individuals for what they did. In other words, the prerequisite for judging the responsibility of individuals is being able to formulate a narrative of their behavior (MacIntyre 1984a, p. 218). However, this idea works in reverse as well; it is reasonable to expect that an actor will be able to provide their own account of their behaviors and intentions (MacIntyre 1984a, pp. 209, 217–218). Holding individuals accountable for their actions in part requires them to explain why they acted in the way they did. Of particular interest in the current context is that such an explanation includes an account of whether one fulfilled one's responsibilities. This explanation will be particularly important when the actions of a practice affect others, one can judge from such accounts the intentions of practitioners and more precisely, the transgressions in question. In formal terms the relevant responsibility can be stated as:

7. Practitioners are responsible for being able to provide an account of their behavior, decisions, and intentions.

Engineering as a Practice

Engineering is a practice. Engineering is cooperative and socially established activity defined by standards of excellence which, when pursued, results in internal goods and an extension of the ends involved (Bowen 2010; Martin 2002; van der Burg and van Gorp 2005). These points about engineering in general are also true for the practice of structural engineering specifically. In this section we illustrate the standards of excellence and internal goods of engineering, focusing specifically on structural engineering. Based on our characterization of structural engineering, we go on to define the responsibilities of structural engineers.

Standards of Excellence in Structural Engineering

It is common to base an account of the responsibilities of engineers on the practice's formal ethical codes such as the NSPE Code of Ethics for Engineers (NSPE 2007). However, this method does not help to discern the responsibilities engineers have *qua* engineers. Codes of ethics are broader in scope and include, for example, responsibilities that are not unique to engineering but constitutive of being a professional. For instance, formal codes of ethics call on engineers to avoid conflicts of interest or not to take bribes. These rules form responsibilities that engineers do have but they are not unique to engineering. Also, standards such as one prohibiting engineers from taking bribes relate to external goods such as money or status. This is the reason that other practices such as medicine or law recognize these standards as well, because they do not require being associated with one particular practice or another.

In our view, technical codes should be viewed as codifying the standards of excellence of engineering. If structural engineering is a practice then it has its own standards of excellence. Immediate sources of standards governing the practice of structural engineering are the practice's technical codes. Technical codes serve as guidelines governing structural design in the materials of concrete, wood, and steel. These codes specify dimensions and grades of materials, so that a target level of safety and performance can be achieved in commonly encountered situations. For instance, technical codes tell engineers the number of nails required to join two pieces of lumber in prescribed configurations. They also tell us the lightest steel beam available for a particular case of loading so that material is saved and strength is ensured. Concrete codes dictate how much steel reinforcing is necessary to avoid sudden failure of structures or how much concrete coverage should be maintained around reinforcement to ensure longevity. Technical codes change in sync with evolution of the practice. They are the direct result of daily activities, such as research and design on the part of engineers in cooperation with each other. Technical codes are unique to engineering because they are developed and approved by engineers themselves to govern the work that defines engineering. The implication of this fact for the purpose of this paper is that technical codes, such as those used in structural engineering, are sources for what engineers are responsible for solely as engineers.

For example, consider the American Institute of Steel Construction's *Specification for Structural Steel Buildings* (American Institute of Steel Construction. 2010). The specification's preface reveals that this design guide.

> is the result of the consensus deliberations of a committee of structural engineers with wide experience and high professional standing, representing a wide geographical distribution throughout the United States. The committee includes approximately equal numbers of engineers in private practice and code agencies, engineers involved in research and teaching, and engineers employed by steel fabricating and producing companies (American Institute of Steel Construction. 2010, p. 16.1-v).

This work is developed and approved by an identifiable body of structural engineers. It is the result of social cooperation in engineering. The code is "based upon past successful usage, advances in the state of knowledge, and changes in design practice (American Institute of Steel Construction 2010, p. 16.1–v)." This is precisely how standards should evolve if engineering is a practice according to MacIntyre's definition. The most recent version of the code gives priority to contemporary methods of structural design such as the direct analysis method. This method takes into account second-order loading effects on steel structures making them more stable and safe. The direct analysis method is made possible by the widespread use of computer analysis tools, and it represents the current standard of practice in structural engineering within the United States. It is the development, maintenance, refinement, and authority of such codes that qualify them as standards of excellence in the terms MacIntyre associates with practices.

Technical codes are standards of excellence because they codify and reflect those standards that have excelled historically (MacIntyre 1984a, p. 189). Someone may argue that these authoritative and formal standards serve only as minimum standards. However, as with the AISC *Specification*, current codes reflect the current state of knowledge and methodologies in the practice. Furthermore, they attempt to strike an ideal balance between a number of design criteria such as safety and efficiency. Consider an instance when a beam is being designed for a building. Though a different size beam may work, the probabilities used to develop the recommendations contained in the specification ensure a high degree of safety, balanced with an attentiveness to efficiency. A stronger beam may offer a greater sense of safety though it would be unnecessarily strong. A weaker beam may work some of the time, or for a limited time, or provide strength but result in undesirable deflections and vibrations. The code offers a way to strike the appropriate balance between the two criteria. Thus the term minimal is misleading because we are talking about an outcome involving multiple variables.

Technical codes are standards of excellence because they play a central role in the defining and evolving of engineering practice. Current codes are revisions of and improvements on past codes. Equally important, improved standards are continually being introduced into codes, as old standards are phased out. Engineers who use outdated codes may over-design. Excellence is achieved by knowing and following the latest versions of the codes. As these codes become common, new improvements in the practice of engineering will replace them. New research and new techniques can come to define part of the standards of excellence when adopted by the practice by being incorporated in the codes.

There are also standards in engineering practice upon which technical codes are founded and more importantly serve as guides for circumstances in which the technical codes are insufficient. These standards are the abstract models of physical phenomenon that engineers develop and use to predict the behavior of their designs. The practical use of scientific or mathematic models to predict the behavior of physical materials so that societal needs can be met is a unique activity and hallmark of engineering Nichols and Weldon 1997). It is what Mitcham refers to as engineering's "'internal' trait of modeling (Mitcham 1994, p. 162)." These models are understood to give the most accurate available prediction of material behavior under prescribed conditions. The most contemporary, accurate, efficient, or appropriate methods of solving an engineering problem depend on the progressive evolution of these models. One example of the progress of such activity in structural engineering, is the transformation from one theory of how to judge the strength of a beam to another. The seventeenth century produced Galilean rules of thumb directing that beams be loaded along their narrow side (Timoshenko 1983). Then came Hooke's explanation of the relationship between material strength and deformation. In the early nineteenth century, Navier showed how theories of elasticity could be used to solve indeterminate beam problems. Shortly after, Cauchy developed a mathematically rigorous model of elastic behavior. With the advent of computers in the twentieth century, the most modern methods of strength determination in beams have been incorporated into software programs doing finite element calculations.

Goods in Structural Engineering

The previously mentioned standards of excellence in structural engineering exist to aid in the achievement of particular, evolving goals of design and research. Internal goods are ends realized by practitioners. What follows is a discussion of several goals of structural engineering that can be construed as internal goods or ends.

There are a number of ideal outcomes that measure the success of a structural engineering project. In ancient civilizations, engineers were responsible for ensuring a prescribed result such as building a monument or constructing an irrigation system. This seemed to be the goal regardless of the human cost of construction and experimental, full-scale failures (Wells 2010). As engineering knowledge progressed and the demands of society became more intricate, the outcomes of engineering work have taken on more clearly defined requirements. In the past several centuries, adequate strength and efficiency of geometries and materials have become outcomes more avidly pursued by means of increasingly specialized knowledge. Serviceability and stability are also now requirements of comparable importance. Safety, not only for end users of structured objects but also for people involved in building and manufacture is also an important consideration. In more recent decades, sustainability in structural engineering has become a conscious goal, particularly for those structural engineers involved in areas of structural health monitoring, diagnostics, and rehabilitation. Though some of these ends are more recent additions to the goals of structural engineering than others, the aims of strength, stability, serviceability, safety, and sustainability are ends or goods that contemporary structural engineers adopt for themselves and work to achieve. They are ideals structural engineers are responsible for pursuing.

The Responsibilities of Structural Engineers

The standards of excellence and goals of structural engineering determine what structural engineers are responsible for in the terms laid out by this paper. They can be summarized in the following way:

1. Structural engineers have the responsibility to know and follow current technical codes of structural engineering practice.
2. Structural engineers are responsible for using the best abstract mathematical and scientific models currently available. This requires knowledge of the current state of design theory, mathematics, and material behavior. To know these models is to both better understand the codes and to have methods to solve problems for which the code makes no recommendation.
3. Structural engineers are also responsible for participating in the process of excelling in meeting practice standards such as models and codes. This does not mean that every structural engineer should have a direct role in revolutionizing current standards of excellence. What it does mean is that all should use the current standards appropriately, where necessary note insufficiencies, and where possible contribute to their improvement.
4. It is the responsibility of structural engineers to articulate problems in the practice and work towards solving them. This responsibility applies to individual engineering projects such as buildings as well as to large scale research projects with broad impacts on the way engineering is done.
5. Structural engineers have a responsibility to understand and achieve the necessary outcomes of a project as expected by authorities such as clients, the

law, and end users. These outcomes, or internal goods as we called them, include strength, sustainability, safety, stability, and serviceability.

There are other responsibilities mentioned in the previous section which are also applicable to structural engineering, although an extensive discussion of them lies outside the scope of this paper. Ethicists have noted that collective support and autonomy are important components of responsible behavior in the professions (May 1996). These components require the support of cohesive community of engineers. Thus, we should consider what it means to live the life of an engineer and to be a part of a community of engineers. By taking these things to be internal goods, issues of collective support and professional autonomy can be placed as goals of engineering. The relevant responsibility for structural engineers can be stated thus:

6. Structural engineers are responsible for participating in a community of structural engineers that supports the practice as a whole.

There are a number of ways engineers can strengthen their community of engineering practitioners. Larry May mentions that professional engineering societies might perform this function (May 1996, pp.117–122). Engineers can participate in conferences, publish papers in professional journals, mentor other engineers, and share their perspectives on their work and the work of their contemporaries. In cases such as whistle blowing, they can offer support to their colleagues.

The next and final responsibility has to do with what MacIntyre has said about putting our actions in narrative form so that we and others can make proper sense of them. For engineers the relevant responsibility can be stated as:

7. Structural engineers have the responsibility to make an account of the relationship between their decision made in the course of their work and standards of excellence and goods of structural engineering.

To make such an account, a structural engineer must be conscious of these elements. One way this is commonly done in practice is by taking notes of research and design processes. Documentation of information and decision-making is a responsibility that many engineers already fulfill. Engineers also write books and articles containing similar narratives of their work. Though these accounts are not rightly available to anyone who might request them, they are important in a number of instances. In actions leading to legal disputes, a narrative of the intentions of structural engineers can be very important. Engineers who fulfill the responsibility to explain their work in terms of standards of excellence and goods also make a contribution to the previous responsibility to participate in the maintenance of an engineering community. There may be other instances where clients or victims of harm are entitled to such an account.

The responsibilities of structural engineers outlined above have been derived from the concepts adopted from MacIntyre. They reflect an attempt to recognize a number of things structural engineers are responsible *qua* engineers. One benefit of looking at responsibility this way is that it is easy to see how the items on this list are interrelated. For instance, engineers who fulfill their responsibilities to achieve standards of excellence also achieve internal goods, while contributing to the fostering of community. In the following section this paper provides a case study to better demonstrate how these responsibilities may or may not be fulfilled in actual practice.

The Sleipner A Condeep Platform Accident

The failure and loss of the offshore Sleipner A Platform in 1991 provides us with an opportunity to examine in practice the responsibilities we have previously ascribed to structural engineers. First, this case study incorporates the use of technical codes governing off-shore structures as well as the use of sophisticated structural analysis methods. Second, how the accident has been interpreted by engineers, investigators, and ethicists reveals the role and importance of narrative account making in engineering work. What follows is a brief description of the accident and a more detailed look at the facts of the situation as they pertain to the previously ascribed responsibilities of structural engineers.

The Sleipner A Platform was a condeep, gravity base type offshore petroleum extraction platform. Condeep platforms are made of concrete and stand tall from the ocean floor to surface. They are used in the North Sea where conditions are harsh and petroleum may need to be stored within the platform structure during winter months (Wackers 2004; Michael Collins et al. 1997). Gravity base structures are designed so that the weight of the concrete is enough to resist the upward force of ocean water displaced by the structure when it is lowered to the bottom of the ocean. The Sleipner A Platform was of moderate size compared to other condeep platforms in operation (Michael Collins et al. 1997; Wackers 2004). It consisted of 24 concrete-walled cylinders, less than 80 m high, and bundled together to appear like a honeycomb in plan (Holand 1994; Michael Collins et al. 1997). Each cylinder was 24 m in diameter (Michael Collins et al. 1997). In the interstices of the cylinders triangular void spaces were created, called tricells (Wackers 2004). In order to raise and lower the platform in the ocean, water levels in the cylinders were controlled through mechanical-pump ballasting. Water levels in the tricells were not able to be controlled in such a way due to the design of the platform. On August 23, 1991, the Sleipner A Platform was towed to deep water for a ballasting test prior to being put into operation weeks later (Holand 1994; Michael Collins et al. 1997; Wackers 2004). During submersion, a crash was heard and the platform began to sink. Roughly 18 min later the platform disappeared into the ocean causing a magnitude 3.0 earthquake near the coast of Norway as the platform hit the ocean floor. All workers on board were evacuated so that there was no loss of life.

Most accounts of the Sleipner accident emphasize the immediate causal and technical factors surrounding the loss of the platform. These accounts emphasis the fact that, once the pressure head difference between the water in the tricells and water in the cylinders reached roughly 65 m, a crack developed between the two causing ballasting controls in the cylinders to fail. The strength of the walls between the two spaces was underestimated so that the walls could not withstand the loads caused by the pressure difference. Hypotheses of sinking scenarios, scale-tests, computer models, and full-scale model tests were all used during the post-accident investigation to conclude that a crack between tricell T23 and cylinder D3 caused the failure. [2]There are two often cited reasons why the walls were insufficient. The first is that when finite element analysis was used to determine the required strength of the tricell wall, standard finite element modeling practices were not followed. Design engineers used a computer model that incorporated skewed finite elements when it was known that such elements can produce inaccurate results (Holand 1994). This led to a 43 % underestimation of the true shear strength required in the wall (Wackers 2004). At the same time, it was concluded that the proper size and placement of shear reinforcement, steel pieces known at T-bars, was insufficient. As this paper will claim, these two problems can be categorized as shortcomings in the areas of formal technical codes and abstract, analytical methods.

A few authors have written accounts of the accident that put the reasons the platform sank into the context of broader narratives. Collins et al. have discussed the fact that concrete codes governing the design of off-shore concrete platforms in Norway were adopted from codes written by the American Concrete Institute (ACI) in the 1970s (Michael Collins et al. 1997). According to the authors, it is known that these codes were insufficient for loading situations such as those that occurred in the tricell wall. The ACI code allowed for a reduction in shear reinforcement in concrete members subject to high compression loads. This allowance was a response to earlier structural failures where an opposite scenario occurred. Concrete members in tension were found to need more shear reinforcement than usual. The authors' point is that it is not always appropriate to assume that compression, the opposite of tension, reduces the need for shear reinforcement. Other concrete construction codes in use at the time, such as the AASHTO code, do not make similar allowances. The authors show through laboratory analysis that if the AASHTO code had been followed, the tricell wall would have likely held. Wackers has written an account that puts the failure of the platform into the context of the economic and corporate constraints imposed upon the project. At the time, petroleum prices were low and the contractor, Norwegian Contractors, was attempting for the first time to do all of the required engineering analysis in-house. So, the market was shrinking at the same time the company was expanding its capabilities. In order to achieve profitability, engineers at Norwegian Contractors focused on saving material costs by optimizing the design, thus making the platform walls as thin and lightly reinforced as possible. The accounts of Collins et al. and Wackers attempt to explain the failure of the Sleipner A Platform in terms which extend beyond the previously mentioned mistakes in finite element analysis and reinforcement placement.

Within these explanations of what caused the Sleipner A Platform to fail, there are issues related to the concepts which this paper has derived from MacIntyre's moral philosophy. First, this paper has previously claimed that formal codes and

[2] Two independent investigative agencies came to the same conclusion. One investigation was conducted by Norwegian Contractors, the company who was under contract to design and build the Sleipner A Platform. The other investigation was conducted by SINTEF at the request of Statoil who owned the lease for the off-shore field where the Sleipner A Platform was to be operated.

analytical methods are standards of excellence in the practice of engineering. Specifically, the codes for concrete construction which influenced the design of the Sleipner A Platform are candidates for scrutiny as codes of excellence in structural engineering. The method of finite element analysis for determining the stress on a structural object was, and is, one of the most advanced methods of analysis in structural engineering. Finite element analysis is a standard of excellence in current structural engineering practice. Second, the internal goods that this paper has previously recognized are central to the incident. Safety and strength are the most obvious goods in question. However, Wackers' account involves another good which complicates the others. This good is optimization. Finally, we can see in the various perspectives and conclusions reached by investigators such as Collins et al., Holand, and Wackers, that a narrative account of why the platform failed helps us to reach conclusions about what the engineers intentions and mistakes were. Holand suggests that the finite element methods used by the engineers were vulnerable to miscalculation. Collins et al. focus upon the codes governing the project as the source of problems. Wackers claims that the engineers did the very best they could possibly do and that the platform failed because of the external constraints imposed upon the design team by their company, their dedication to the ideal of optimization, and the economic conditions of the time. Recognizing these three points helps us to sort out the responsibilities of structural engineers *qua* structural engineers. In the remainder of this section, this paper will focus on these three issues as the bases for responsibilities in structural engineering.

In the terms ascribed by this paper, we can make a statement regarding what the engineers ought to have done or should do in similar situations. First there are those responsibilities that this paper has formed around knowledge and use of technical codes. Collins et al. have stated that the engineers at Norwegian Contractors followed the applicable Norwegian codes for concrete design. However, part of the failure of the Sleipner A Platform can be traced to the fact that the Norwegian codes were adopted from a version of the ACI code. The ACI code had a history of its own which led to its insufficiency under the particular circumstances in question, namely when a compression member is subjected to high shear forces. It is the responsibility of engineers to understand that codes are adopted for common problems as the American Institute of Steel Construction's *Specification for Structural Steel Buildings* states the "intention to provide design criteria for routine use and not to provide specific criteria for infrequently encountered problems, which occur in the full range of structural design (American Institute of Steel Construction 2010 p.16.1–v)."

It is also the responsibility of engineers to understand the source and history of technical codes. This brings us to our second responsibility. Structural engineers have the responsibility for understanding and working with the analytical models on which the codes are based. These models are also important for unusual instances where the standardized codes do no apply. Though engineers on the Sleipner A Platform design team did use the analytical methods of the time, finite element analysis, they failed to follow the finite element methods rigorously. The engineers used skewed shaped elements in their finite element model when standard practice recommended against this. This responsibility should have been higher prioritized because the Sleipner A Project was the first time Norwegian Contractors had conducted their own finite element analysis in-house (Wackers 2004).

In the case of the Sleipner accident, it is evident that knowledge of the tradition of engineering would have helped engineers discern which standards of excellence apply in particular situations. Knowing the history of the concrete theories and codes could have led engineers to see that the codes in use were adopted from a source that was not adequate to their application in the Sleipner design, namely that high compressive forces meant shear reinforcement could be lessened. Also, knowing the theory and best standards of finite element analysis could have led engineers to use the analysis properly because they would have understood the dangers of using skewed elements. They also would have known that rudimentary methods existed for identifying errors in the finite element calculations. As MacIntyre points out, an adequate knowledge of tradition is a virtue which gives practitioners the ability "to select among the relevant stack of maxims and how to apply them in particular situations (MacIntyre 1984a)." This reaffirms the importance of traditions as it has been used in this article.

Wackers claims that the engineers on the project were doing the best job they could under the circumstances. This paper finds that they were still ethically responsible for the mistakes they made which led to the failure. For instance, they failed to understand engineering standards sufficiently to know what standards, such as those governing finite element modeling, were crucial to success and what standards, such as concrete codes, were inappropriate for the problem at hand.

Wackers' point that the economic and corporate circumstances in which the engineers worked made it difficult for them to behave otherwise is a good one. This paper takes the position that this does not absolve them from responsibility ascriptions as structural engineers. They may receive criticism from their peers or professional consequences. However, when financial liability was ascribed it was more appropriate to take action against the company, Norwegian Contractors, and not the individual engineers in part because decisions by other participants, such as business managers, did contribute to the problem.

The Sleipner A Platform accident raises an interesting question about how structural engineers are responsible for internal goods or ends. In this instance, structural engineers were not able to ensure strength or safety. As Wackers points out, they were dedicated to the internal good of optimization. However, it is clear that optimization cannot be considered an outcome of a structural engineering project where strength and safety are not achieved. These facts raise three questions. First, if internal goods conflict in such a way are they really internal goods? Second, are there internal goods in structural engineering, such as strength, which are more important than others? Lastly, would structural engineering be what it is if strength was an internal good but optimization was not? This paper takes the position that structural engineers are responsible for more than adequate strength and this includes optimization, which is the same as efficiency that this paper previously established as a good. These questions need not be answered here in full, because it is part of responsible engineering practice to continuously pose and debate such questions.

The Sleipner case and the referenced investigative accounts into what caused the accident also highlight the responsibility engineers and engineering ethicists have to make accounts of their intentions, decisions, and actions. The investigations that took place after the accident were intently focused upon finding the source of the structural failure. The key reason this is so is because a new platform had to be built immediately. Despite this motivation, engineers at Norwegian Contractors, engineers in research groups at universities, engineers working for independent investigators, and engineering ethicists did work to produce narrative accounts that made the accident intelligible in a broader context. To make an account of their actions is a responsibility of structural engineers, and in this case fulfillment of this responsibility had several positive consequences. First, the accounts made it possible to build a new platform. Second, the accounts serve to educate other engineers about their future actions. It is now easier to see the danger of skewed elements in finite element analysis. It is also easier to grasp the shortcomings of certain concrete codes governing the design process. Making these points explicit contributes to the responsibility structural engineers have to expose problems and seek solutions to those problems. All of these outcomes contribute to the evolution of what constitutes excellence in structural engineering. When practitioners fulfill these responsibilities, they are furthering the standards of excellence and internal goods of their practice in the manner discussed by MacIntyre.

The Sleipner A Platform accident provides us with an opportunity to establish what the structural engineers on the project should have done but more importantly, what structural engineers should be doing in current practice. Engineers must understand and follow the technical codes of their practice. In addition, they must know the limitations of those codes and more importantly, the theories of engineering that supplement and underlie the codes. Engineers are responsible for achieving the internal goods of their practice. Fulfilling their responsibilities to technical codes and analytical methods does this. Making accounts of their intentions and decisions is a responsibility that allows others to judge how the other responsibilities have been fulfilled. All of these responsibilities are integral to what engineers do, that is identify and solve material problems.

Conclusions

This paper has argued for a specific account of the responsibilities of engineers *qua* engineers, in particular structural engineers, by considering engineering as a practice with its own standards of excellence and internal goods. The concepts we have adopted from Alasdair MacIntyre's moral philosophy have been used to identify what engineers ought to do. These concepts include practices, standards of excellence, internal goods, and traditions.

First, this paper established engineering as a practice as a starting point for determining what engineers should be responsible for simply as engineers. Technical codes, analytical methods, and abstract models are standards of engineering that do represent excellence in the practice. It is important for engineers to maintain these standards as excellences by continually working to know them thoroughly, successfully implement them in practice, identify shortcomings of the standards, and improve upon them. This paper also proposed a number of internal goods of the practice, characteristics reflected in the products of engineering. In structural engineering these goods are strength, serviceability, stability, safety, and efficiency. The case of the Sleipner A Platform accident raised the question of how these goods should be ordered and prioritized. These questions may remain unanswered here; it is the job of practitioners to debate their function and importance to the practice. Knowledge of the tradition of which one is a part fosters responsible behavior. Practitioners inherit responsibilities from the previous practitioners in the history of the practice. They also inherit problems to solve. Solving these problems leads to the furthering of standards and goods.

It is the responsibility of engineers to pursue and achieve excellence in engineering. When this is done, engineers fulfill the ethical obligations they have to society as engineers. This does not mean that they do not have other responsibilities to society outside of their roles as engineers. However, it is apparent that if technical standards of excellence are followed with the intent of achieving internal goods, such as safety and efficiency, then both social and technical obligations can be met, and outcomes which better society can be achieved.

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