

Seismic Shifts and Retrofits: Scale and Complexity in the Seismic Retrofit of California Bridges

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Introduction

Infrastructure systems play a crucial role in the relationship between humans and the natural world, in part because they are the only human technological systems built on a large enough scale to have geophysical relevance (Edwards 2003). Many of the chapters in this book focus on infrastructure retrofit as a means to reduce human impact on the environment. This chapter instead focuses on retrofit to protect human beings from their environment: specifically, seismic retrofit of bridges to prevent them from collapsing in earthquakes. Although the impetus for retrofit may differ, the program discussed here raises many issues that are likely to be relevant for any kind of large-scale retrofit program that impacts urban settings. In particular, it provides examples of the complexities that arise in implementing a systemic retrofit program (May *et al.* 2013). This kind of systemic effort can be particularly complex because of the tension between global and local aspects of retrofit. At a global level, such a program must attend to the factors that sustain a systemic effort, such as engineering standards, funding sources, and political support. At a local level, each individual retrofit project has the potential to become entangled in localized contingencies of communities and the built environment. This paper examines the characteristics of infrastructure that play into this global-local tension, the processes by which changes in sociotechnical systems become mobilized as worrisome problems, and the resulting practices of infrastructure repair, of which retrofit is one variety.

Infrastructure Retrofit

This chapter is primarily about retrofit of infrastructure technologies, in particular those that are locally massive and difficult to change, such as buildings, roads, and bridges. Compared to other technologies, infrastructures are unique in the fact that they are *globally embedded*: they have broad, global reach but are simultaneously deeply embedded within local practices and systems, to the point where they can become almost invisible if they are working properly (Star and Ruhleder 1996, Bowker and Star 1999, p. 35). This tension between local and global scales accounts for much of the complexity involved in both developing and retrofitting infrastructure systems. Bridges and overpasses, for example, must function as part of a larger road system that is built to certain universal standards, such as minimum lane widths, allowable vehicle weights, and road surface characteristics. At the same time, however, each structure has to be designed to accommodate the unique form and characteristics of the land beneath it (hence the specialty of geotechnical engineering), and to integrate into other local infrastructure configurations - for example, an overpass might have to be built without impacting local sewer lines, or may be required to carry gas lines or electrical cables. After structures are built, they tend to become

increasingly integrated with other local systems and practices (Hommels 2005, Sims 2007a, 2007b, 2009), which, in some ways, makes retrofitting infrastructure components more complex than building them in the first place.

In a more general sense, we can understand infrastructures as networks that manifest themselves in different ways at different scales across a range of locales and social worlds (Edwards 2003). Although many infrastructures are widely understood to be networks in a material or logical sense, they also exist in the context of heterogeneous sociotechnical networks of people, things, ideas, documents, etc. - what Bruno Latour and others call “actor networks” (Latour 1987, 1996). At a global administrative level, for example, bridges and overpasses are embedded in a network that includes regulations and standards (for example, those associated with the interstate highway system), government budgets and elected officials, and broad public interests, such as those of commuters. At an engineering level, they are associated with networks that include engineers from a variety of professional specialties (structural engineering, traffic engineering, landscape engineering, etc.), managers and organizations, design methods, building practices, and computer codes and software. At a geographically local level, they are part of networks that include other infrastructure components; local communities that may have opinions about things like traffic, bike lanes, and aesthetic impact; and environmental conditions like soil settlement and runoff from nearby surfaces.

A key problem for any systemic retrofit program is managing the tension between the global and local networks it interfaces with (Law and Callon 1992). To explore how this works in practice, I use the example of the California Department of Transportation (“Caltrans”) seismic retrofit programs of the 1970s, 80s, and 90s (Sims 1999, 2000).¹ This retrofit process was driven by a series of earthquakes that damaged bridges in ways not anticipated by Caltrans bridge engineers, which coincided with rapid changes in engineering knowledge about how structures respond to dynamic forces like earthquakes, making many existing bridges appear dangerously obsolete. This led to efforts to retrofit bridges, which culminated in a massive state-wide retrofit program following the 1989 Loma Prieta earthquake, a major temblor which caused extensive damage to freeway structures in the San Francisco Bay Area.

To better explain how retrofit programs interact with global networks, the first Caltrans case study below covers changes in general engineering practice at Caltrans from the 1970s through the 1990s, and its relationship to broader political and professional networks. The second Caltrans case study focuses on the sociotechnical network surrounding one particular project, the seismic retrofit of the Coronado Bridge in San Diego, which illustrates the complexities that can attend local implementation of a systemic retrofit program.

Sociotechnical Repair

Retrofit can be understood within a larger context of “sociotechnical repair,” as articulated by Henke and Sims (Henke 2000, 2007, 2008, Sims and Henke 2012; see also Graham and Thrift

2007 and Jackson 2014). We conceptualize repair as an ongoing sociotechnical process that is essential to maintaining the perceived stability of sociotechnical systems.² Both social and technological aspects of repair are important to consider because they often happen concurrently. For example, a chemical company that has experienced an accident may work to fix the technological systems and organizational processes that led to the accident, while simultaneously using these repair efforts as part of a discursive effort to repair the company's public image. For simplicity, for the remainder of the chapter I will refer primarily to technological systems, with the understanding that humans generally are part of these systems in one way or another.

Technological systems are not inherently stable entities. Instead, they can best be viewed as dynamic processes in which system functionality, internal coherence, and boundaries are accomplishments that, once attained, are in constant danger of being lost in the ongoing interplay of social and technological forces. Repair practices are fundamental and ubiquitous because they are the key to stabilizing technological systems. Paradoxically, they also play a major role in technological change, because vast numbers of relatively small repair efforts can, in aggregate, lead to significant historical trends.

Slippage, Repair, and Retrofit

Sociotechnical repair is often motivated in terms of a kind of “slippage,” over time, between beliefs about a technological system's current state, and ideas about how it ought to be functioning. The first are often presented in objective terms, based on studies, measurements, or observations; the second are usually presented in more normative terms, prescribing an idealized system state.

In the context of infrastructure, the current condition of a system might be described in terms of structural integrity, network redundancy, usage patterns, or interfaces with other infrastructure systems and the natural environment. These are often expressed in terms of measurements against a given scale. The normative view of system functionality might take the form of specifications and margins expressed in these same measurement scales, which themselves are often embodied in complex technical standards and building codes. It may also be expressed in more overtly moralistic terms, in terms of aspirations, goals, redress of grievances, and judgments about the societal role of infrastructure and its designers and builders.

Slippage is a useful way to analyse breakdown and repair because these processes are typically framed in terms of change from some pre-existing equilibrium – either a return to an equilibrium that has been disrupted, or adjustment of an equilibrium in anticipation of future threats to stability of a system. There are two ideal types of slippage: degradation and obsolescence. Degradation is when normative expectations remain stable, but objective conditions are seen as having changed, or being in danger of changing: for example, a building has sustained earthquake damage, a bridge's paint has a five year life span, or call volumes on a mobile phone network are expected to increase. Repair, in cases of degradation, is usually described in terms of

maintenance, restoration, or what we might call “simple” repair of something that is broken: fixing earthquake damage, initiating a preventive maintenance schedule, adding cellular communication towers.

The other ideal type of slippage, obsolescence, is when objective conditions are perceived as stable, but normative expectations have changed: for example, engineering standards and building codes have been updated, there is a movement to add bike lanes to existing bridges, broadcasters want to transmit high definition television signals. Existing technology comes to be seen as outdated or not responsive to social needs.

In most cases, particularly in the global North, obsolete technological artifacts are simply destroyed or thrown away, and replaced with something that meets current standards. The less common alternative is to retrofit existing artifacts. This possibility generally comes into play only when, for whatever reason, the destruction or disposal of existing technological artifacts is perceived to be costly or otherwise undesirable. In the global North, the cost of replacement has generally been an insurmountable issue only with fixed, massive infrastructure components like buildings and bridges. However, particularly in the context of energy efficiency, the environmental cost of complete replacement of existing artifacts has become more recognizable, which in many cases shifts the balance in favour of retrofit. Retrofit may also be preferred in situations where the problematic technological artifact has historic or aesthetic significance.

In the broader context of sociotechnical repair, then, retrofit is a specific kind of repair that generally occurs when normative standards for technology change under conditions that limit our ability to replace existing technological artifacts. In these cases, we are no longer just fixing something that is broken, we are essentially going back and rewriting history by altering past technology to fit current technical standards and social needs: tying down old houses to their foundations more securely to meet current seismic safety standards, making bridges wider to accommodate bike lanes, changing broadcasting systems and receivers to support digital television.

Problematizing Obsolescence at Caltrans

The history of seismic design and retrofit of bridges at Caltrans provides useful insight into the complexities of problematizing a technology as obsolete and in need of retrofit. In particular, it illustrates the complex interplay between 1) actors, 2) objects and events, and 3) knowledge during periods of significant change in a sociotechnical network. During the time period discussed here, the sociotechnical networks surrounding bridge design both expanded and experienced significant changes in their composition. As engineers’ understanding of seismic performance of bridges changed, specific elements of these structures emerged as “risk objects” within the network (Hilgartner 1992). (In Caltrans parlance, “bridges” refers to a range of objects, from small overpasses to large toll bridges like the Coronado Bridge and the Golden

Gate Bridge. In this portion of the case study, “bridges” refers mainly to reinforced concrete overpasses, freeway ramps, and elevated road structures.)

In the Caltrans case, there appear to have been three key conditions that led to decisions to retrofit, which may be generalizable to other infrastructure retrofit decisions. First, there was slippage away from the knowledge, practices, and norms that were in play within the relevant networks when the technology was created. Next, based on this slippage, a specific set of technological artifacts or systems was identified as obsolete. Finally, the obsolescence was articulated as a risk or problem in a public arena that included relevant decision makers and stakeholders, enabling negotiation of access to sufficient resources to carry out a retrofit program.

It is useful to think in terms of three broad eras in the articulation of earthquake risk to bridges within Caltrans networks. First, prior to 1971, earthquake risk was acknowledged, but played a relatively small role in the design and construction of bridges. There was little understanding of how bridges might respond dynamically to earthquakes, design standards generally required little reinforcement beyond that needed for a bridge to support traffic, and engineers had had little or no opportunity to observe earthquake impacts on bridge structures. In 1971, a major earthquake in the San Fernando Valley, near Los Angeles, damaged bridges in a freeway interchange under construction, revealing unexpected weaknesses. This ushered in a second era of risk definition, in which certain specific design details were recognized as problematic, the dynamic response of bridges to earthquakes became better understood, and a minimal retrofit program was undertaken. The third era of risk definition followed the Loma Prieta earthquake that caused extensive damage in the San Francisco Bay Area in 1989. This included the collapse of the Cypress Viaduct freeway structure, which killed 41 people and finally associated obsolete bridges with danger to the general public (Governor’s Board of Inquiry 1990, p. 27). This brought political decision-makers, the media, and dramatically increased financial resources into the Caltrans bridge engineering network, which led to an era of massive change at Caltrans, in which the network expanded to include members of the earthquake engineering research community, new design methods and tools, and a massive retrofit program for state bridges.

The network prior to 1971

Prior to 1971, the significant actors in the Caltrans bridge engineering network were primarily Caltrans engineers themselves; there was little interaction with engineering researchers, and very little useful research had been conducted on earthquake impacts to reinforced concrete structures. In addition, there had been very little systematic observation of how actual earthquakes damaged structures, so earthquakes and earthquake damage were not significant objects within the risk network. The state of the art in seismic design practice was to calculate whether a bridge could stand up to a static horizontal force equal to some percentage of its own weight, depending on the nature of the bridge footings and underlying soil (Governor’s Board of Inquiry 1990, p. 122). In most cases, bridges that were designed properly for the weight of traffic would have already

met seismic design criteria (Governor's Board of Inquiry 1990, p. 123). This slowly began to change in the late 1960s, when it was discovered that taller, more slender structures, with longer natural periods of vibration, were less susceptible to earthquake damage (Governor's Board of Inquiry 1990, pp. 122–123). This enabled engineers to reduce the horizontal force requirements for most bridges. At the same time, early computational tools made engineers more confident in designing bridges with lower margins of safety. As a result, bridges became more aesthetically interesting, but in retrospect actually less able to resist earthquakes (Sims 2000, p. 42). None of these changes called into question the safety of older bridges, so Caltrans engineers did not view older structures as posing any special risk. Up until 1971, no notable earthquake damage had been observed in modern concrete bridges in any case, and there appears to have been little or no public interest in the seismic design of bridges.

1971-1989

In 1971, a 6.6 magnitude earthquake shook the San Fernando Valley, then a rapidly-developing suburb of Los Angeles. At the time, Caltrans was in the process of building two major freeway interchanges in the area, and large portions of several finished (but not yet in service) structures collapsed in very dramatic fashion. The extent of damage caught Caltrans engineers by surprise. The bridges were new, designed to the latest standards, and were expected to be able to withstand an earthquake of this magnitude. This led to an internal investigation and the beginnings of a major rethinking of seismic design standards (Sims 2000, p. 43).

The most obvious change in the bridge engineering network in this era was the inclusion of specific instances of earthquake damage to bridges (Sims 2000, pp. 52–57). Caltrans created formal procedures for investigating damage to bridges after earthquakes; at the same time, earthquakes began to impact bridges more frequently, mainly due to the massive expansion of the California freeway system in the 1960s. Investigations into the San Fernando earthquake, and subsequent events, changed the knowledge and practices of Caltrans engineers in significant ways. Engineers observed two damage mechanisms in the San Fernando event. First, they noticed that the roadways had come apart at joints between segments of the bridges, allowing sections to fall. Second, they saw that the steel reinforcement (“rebar”) in the concrete columns had ruptured, leading to collapse of columns (Sims 2000, pp. 44–45).

The first observation led Caltrans engineers to think about ways of preventing roadway joints from separating, and an inexpensive solution was quickly devised: drill holes in the ends of the bridge segments and tie them together with steel cables. This led to the first Caltrans retrofit program, a low-cost, low-priority effort to install “hinge restrainers” that continued slowly through the 1980s (Sims 2000, pp. 48–51). This effort was small enough that it could be carried out without expanding the bridge engineering network to include actors with access to resources outside Caltrans.

Ductility is the ability of a material or structure to deform beyond the level where it springs back elastically without losing strength. For example, a paper clip can be bent into many different shapes without losing its integrity because it is made out of steel, a very ductile material. In the 1960s and 70s, engineers were just beginning to understand the importance of ductility in earthquake resistance. New research showed that the key to ductility in concrete structures was not just reinforcing them with sufficient steel rebar, but the specific configuration of the steel. In particular, it was recognized that concrete itself could behave in a more ductile manner if it were tightly confined within a cage of rebar, and that the continuity of horizontal reinforcing hoops was crucial to this ability (Sims 2000, pp. 46–47).

As a result of the San Fernando earthquake, Caltrans engineers retooled their design standards based on this new research. The new standards required a continuous spiral of horizontal reinforcement for the entire height of a bridge column, which corresponded to a 5- to 8-fold increase in horizontal reinforcement, as well as improved continuity in vertical reinforcement. These changes were all at the level of what engineers call “design details”; Caltrans engineers still did not understand how to incorporate ductility into design in a comprehensive way (Sims 2000, pp. 47–48).

At this point, it was recognized that existing bridge columns did pose a potential risk, but there was no immediate column retrofit solution available, little funding available beyond what was being spent on the more urgent joint retrofits, and still little public interest in the earthquake resistance of bridges.

Toward the end of this era, in the mid-1980s, the actors represented in the Caltrans risk network began to change in small but important ways. Specifically, Caltrans began to fund research at California universities. In 1984, they funded a University of California, Los Angeles researcher to test hinge retrofit designs (Sims 2000, p. 73). More significantly, the University of California, San Diego (UCSD) hired Nigel Priestley, a world-renowned researcher in earthquake resistance of concrete structures from New Zealand. Caltrans engineers were already aware of Priestley’s work and were eager to collaborate with him. Of particular interest was research Priestley had done on reinforcing bridge piles with steel jackets. Steel jackets rapidly emerged as a leading possibility for retrofitting existing bridge columns: the jackets could be put in place around the columns, and the intervening space filled with concrete, increasing the confinement of the concrete and the ductility of the columns (Figure 1). Caltrans obtained a small grant to begin research on this technology, but had just begun thinking about a retrofit program when the Loma Prieta quake hit in 1989 (Sims 2000, pp. 61–63).

<<< FIGURE 1 ABOUT HERE >>>

This era, then, introduced several significant new objects into the Caltrans bridge engineering network, most notably earthquakes themselves and their impact on actual bridges, with joints and columns as key locations of risk. This led to increased understanding of the importance of

ductility, and changes in design practice, albeit primary at the detail level. Most importantly, Caltrans engineers recognized a slippage between their new design standards and existing structures, identified the older structures as obsolete in significant ways, and associated that obsolescence with a risk of bridge collapse. This led to the hinge restrainer retrofit effort, inquiries into column retrofit, and expanded relationships with university researchers. But the risk of earthquake damage to bridges in California was still very much a local problem, understood by Caltrans engineers and a few others, but not much discussed in wider professional or public arenas.

After 1989

The 6.9-magnitude Loma Prieta earthquake struck on October 17, 1989. The majority of deaths that occurred in the quake were the result of the collapse of the Cypress Viaduct, a reinforced concrete structure that carried a portion of Interstate 880 in Oakland. For the first time, this tied seismic design of bridges to the real possibility of bodily harm, in the eyes of the public, and briefly led to intense media scrutiny of Caltrans design practices. Governor George Deukmejian and other political figures claimed that they had been told that all freeways in the state could withstand an earthquake of this magnitude (Sims 2000, p. 97). These political figures, and the media, initially tried to frame the Cypress Viaduct collapse as a “moral disorder” story - a story in which disaster was tied to human errors or misjudgements, and where blame was to be apportioned accordingly (Sims 2000, pp. 93–97). Initially, it appeared that Caltrans might take the blame. Fortunately for Caltrans engineers, they were able to develop contacts in the media, and their work on retrofit in the 1970s and 80s provided a useful alternative narrative, one in which Caltrans had developed the knowledge and techniques needed to make bridges safe, only to be stymied by lack of money and political interest. This ended up being the dominant frame for the story, and as a result political actors hastened to provide Caltrans with a large amount of money to undertake a comprehensive, state-wide seismic retrofit program (Sims 2000, pp. 99–105). The Governor also appointed a Board of Inquiry, which was made up largely of engineers and ended up being primarily an intra-professional effort, focusing on engineering explanations for the failures rather than apportioning blame (Sims 2000, pp. 105–124).

The effect of these developments was to provide political and media validation of the bridge engineering network and risk objects that Caltrans bridge engineers had developed in the 1970s and 80s. In fact, Caltrans engineers felt they had learned nothing new from the collapse of the Cypress Viaduct, whose inadequacies were readily understood. The bridge engineering network grew by adding political and media actors to the mix, but no new objects or practices were introduced. At least, this was the case initially. The actual retrofit effort led to dramatic changes in these aspects of the network.

One key change was a dramatic expansion of the number of actors in the bridge engineering network, to include practicing engineers and academic researchers throughout (mainly) the state of California. Caltrans employed peer review panels to validate their retrofit plans for specific

structures. For several important structures, these peer review panels acted less as independent reviewers and more as collaborators in the design process. They began to insist that Caltrans use more sophisticated design methods that more precisely incorporated ductility into the design process, which they then helped implement (Sims 2000, pp. 132–165). Nigel Priestley, of UCSD, played a particular prominent role, and his work served as a touchstone for the retrofit program, to the extent that an internal Caltrans memo reported that “designers feel they are to do what Nigel Priestley recommends because they feel management is behind his opinion” (Sims 2000, p. 187). At the same time, Caltrans started funding research on earthquake engineering at a number of universities, including UCSD and UC Berkeley, bringing researchers into the risk network in yet another way (Sims 2000, p. 74).

The new design methodologies had two elements. First, Priestley and another professor at UCSD, Frieder Seible, introduced Caltrans to a method called “displacement ductility analysis.” Without getting into technical details, this approach enabled engineers to design structures with controlled areas of deformation that could be built with the required ductility to remain intact during an earthquake. This approach finally enabled Caltrans engineers to incorporate ductility into the design process in a systematic way. At the same time, Caltrans engineers began using more sophisticated models of entire structures that incorporated the displacement ductility approach (Sims 2000, pp. 174–178).

These new methodologies required Caltrans engineers to work in new ways. In particular, new computational tools were required. One younger Caltrans engineer, who had recently completed his PhD, began developing tools for displacement ductility analysis, but initially had to do so on his own time because bridge engineers were forbidden from writing their own computer code. This situation was soon resolved, and by the mid-1990s, most of the bridge engineers were using his codes as part of their design process (Sims 2000, pp. 179–181). Up until the mid-1990s, even as the retrofit program was in full swing, the new design methodologies were surprisingly informal, spreading across the organization primarily through the circulation of memos, unofficial guidelines, and computer software, and gaining legitimacy primarily through peer review. They were gradually moulded into increasingly formal documents and eventually into official design standards by the end of the 1990s. This formalism defined a new, relatively stable state of the art (Sims 2000, pp. 181–197).

Caltrans’ funding of academic researchers also introduced significant new objects into the risk network, in the form of laboratories and test specimens. Many of the new design and retrofit approaches were validated directly through testing of models of Caltrans structures in the laboratory, in many cases at a scale close to that of the actual structures. These large test specimens had to be built by technicians with actual concrete building experience, designed to correspond to actual or proposed Caltrans designs, and manipulated with very large hydraulic jacks and “shake tables.” This helped ground the new design methods very concretely in structures that were representative of what Caltrans actually employed in the field, freeing

engineers from having to wait for actual earthquakes to test their designs (Sims 1999, 2000, pp. 202–247).

The history of seismic retrofit at Caltrans shows how changes in the makeup of sociotechnical networks can introduce destabilizing elements that leave parts of the network in tension with others. In the hinge restrainer retrofit program of the 1970s and 80s, the tension that emerged was between new engineering understanding of what an earthquake-safe bridge looked like, and already-constructed bridges that could not easily be rebuilt. This tension was articulated as a problem internally at Caltrans, and was inexpensive enough to be carried out with available resources. After the Loma Prieta earthquake in 1989, a new tension emerged between public expectations of how bridges would perform in earthquakes, and the reality of how existing bridges actually performed in a large quake. This new tension shifted the slippage into a public and political realm, where a case could be made for committing more significant resources to a retrofit program to solve the problem. The public controversy phase was, however, very brief and never evolved to include a wide range of interest groups. This may have been because the existing bridge engineering network was so thoroughly dominated by Caltrans engineers, and already provided a coherent narrative to explain events. Ultimately, no other actors came forward with the resources to challenge that narrative. This appears to be a common pattern in professional involvement in public controversies (Gusfield 1981, pp. 10–15, Abbott 1988, pp. 59–85).

The large changes in the Caltrans bridge engineering network after 1989, however, raise an interesting point: Retrofit is not necessarily the end of a process of slippage and realignment in networks. Instead, in this case, retrofit actually opened up the network to additional changes, such that reaching closure on the retrofit process involved a complex convergence between the form of bridges and evolving technical norms, rather than retrofitting bridges to meet a clearly defined set of criteria.

Negotiating Urban Retrofit: Chicano Park and the Coronado Bridge

The changes to the Caltrans bridge engineering network that have been discussed to this point in the chapter mainly relate to the interface of that network with more global networks, in particular California state politics, the engineering research community, and a variety of earthquake impacts on bridges. The actual implementation of individual retrofits, however, required extension of the network into localized environments, often in infrastructurally dense urban settings. This required a very different problem-solving approach from what was required to come up with general engineering approaches to retrofit, including extensive review of “as-built” plans (if they were even available), inspection and measurement of the existing structure, identification of possible co-located utilities, coordination with relevant state and local agencies, assessment of potential environmental and cultural impacts, and ultimately design of retrofit systems customized to the form of the bridge in question. This was a particularly complex

process in the case of large, architecturally significant structures like San Diego's Coronado Bridge (Suchman 2000).

The initial design and later retrofit of the San Diego-Coronado Bridge exemplifies the many ways infrastructure projects, and retrofits in particular, can become complexly entangled in localized social and technological arrangements. This bridge is a major structure connecting the city of San Diego to the "island" of Coronado, across San Diego Bay. Coronado, which is actually attached to the mainland by a thin strand south of San Diego, hosts several military facilities and is home to many military personnel, and also features a number of resort hotels. The bridge was built in the 1960s with the support of Governor Edmund G. Brown, a champion of bridge-building as a tool of economic development. Various local groups were opposed to building a bridge, including Coronado residents who protested the bridge because they feared it would destroy the small-town character of the island. In addition, the Navy initially opposed a bridge because it might interfere with ship movement in and out of San Diego Harbor. They later softened their opposition, but insisted on at least 200 feet clearance over the main shipping lane. In order to accommodate this height without making the bridge too steep, engineers designed the bridge with a 90 degree curve in the middle to increase its length (Fisher 1996, pp. 2–3, Sims 2000, pp. 265–266).

One major interest group was not accommodated in the design process, however: the community of Barrio Logan, a largely Hispanic neighbourhood at the San Diego end of the bridge. Because shipping lanes were closer to the San Diego side, the highest portion of the bridge was built on the San Diego side. In addition, the bridge had to connect to Interstate 5, a quarter of a mile inland, which also required construction of a large complex of ramps and overpasses connecting the freeway to the bridge. For various reasons, it was decided that the bridge should come ashore at Barrio Logan, and a wide swathe of the neighbourhood was levelled to build the interchange. In contemporary accounts, however, this is never mentioned; Barrio Logan was invisible to decision-makers and the media. One of the architects of the bridge later explained that the area was simply seen as a "path of least resistance," with low property values and little potential for political mobilization (Sims 2000, p. 266).

By the late 1960s, however, Chicano political activism was on the rise nationally, and was becoming particularly important in California. The Barrio Logan community, which had already suffered through numerous policy and infrastructure projects that threatened its integrity, was in the midst of a political awakening. The pivotal moment came when the state announced plans to build an enormous California Highway Patrol station on the already desolate land under the bridge and approach ramps. The community, which had had an unhappy relationship with police, was finally pushed over the threshold into dramatic political mobilization. A group of several hundred residents occupied the construction site for twelve days, preventing construction from proceeding and demanding that a community park be built instead. The state backed down, and entered into negotiations with the city of San Diego that eventually resulted in the establishment

of what became known as “Chicano Park” under the bridge interchange (Coffelt 1973, Brookman and Gomez-Pena 1986, Fisher 1996, pp. 13–14, Sims 2000, p. 269).

The park became a focal point of community activity, but remained a noisy and sometimes gloomy place, dominated by the grey concrete of the bridge structure. Partly to combat this gloominess, a loose coalition of local artists conceived the idea of painting murals on the approach ramp columns in the park. Over next thirty years, at least 40 brightly-coloured, symbolically-dense murals were painted on the columns by artists from San Diego and throughout the Southwest (Figure 2) (Fisher 1996, pp. 17–19).

<<<FIGURE 2 ABOUT HERE>>>

The design and construction of Chicano Park, and the painting of its murals, was itself an urban retrofit project, taking a grim, unloved space and reclaiming it as a meaningful centre of community activity and political awareness. The community identified a slippage between the actual form of the bridge and their ideals of how a community ought to be considered in infrastructure decisions, identified it with clear harm to the community, and through civil disobedience, forced the city and state to incorporate the wishes of the Barrio Logan community into future decisions about the bridge. Here, the constraint that led to retrofit, rather than replacement, was that the community did not have anywhere near the political power to effect the actual removal of the bridge, so instead focused on improving the existing artifact in ways that mitigated its terrible impact on the community. The fact that the improvements were largely aesthetic in nature in no way diminishes the significance of this retrofit. Thirty years later, this retrofit would come into conflict with the larger, systemic, technical, state supported Caltrans seismic retrofit program.

When the Coronado bridge finally came up for retrofit in the mid-1990s, Caltrans officials and engineers, as well as the San Diego-based engineering firms designing the retrofit, were aware that the murals could pose a problem, but do not appear to have been aware of the depth of the community’s commitment to the artwork and the degree of political difficulty that could attend any disruption of the park. In order to get ahead of the issue, Caltrans held public meetings early in the design process, at which they presented a range of possible retrofit measures, most of which would have had a significant impact on the murals — including completely replacing the columns, encasing them with steel jackets, and thickening the existing columns in the lateral direction. Decades of community mistrust of Caltrans came to the surface immediately, and community activists began to dig in their heels for a fight. Some questioned whether the bridge really needed to be retrofitted at all. An artists’ group sent out a newsletter demanding “no retrofit, not now, not ever!” A mural was painted in Chicano Park with the prominent message “No Retrofitting.” In sharp contrast to the invisibility of the Barrio Logan community during the building of the bridge, local politicians and newspapers soon took up the cause of preserving the murals (Sims 2000, pp. 270–272). The message of slippage between existing bridges and evolving design standards, and its associated risk to human life, that had worked so well at the

state political level began to lose its power amid the local contingencies surrounding Chicano Park and the bridge interchange.

Seeing that discussions were not going well, San Diego-based Caltrans environmental planners, who saw themselves as having a better grasp on local politics and concerns about the retrofitting, began to take a much more aggressive role in courting community leaders, holding numerous additional public meetings throughout the course of the retrofit development. At the same time, Caltrans historians and archaeologists who developed the required environmental impact documentation for the project had come to the conclusion that the murals probably qualified for inclusion in the U.S. National Register of Historic Places, further complicating matters. Indeed, the laws like the U.S. National Environmental Policy Act (NEPA) are one reason why the political processes surrounding infrastructure have changed so significantly since the time when the Coronado Bridge was initially built, and are a key point of leverage for communities like Barrio Logan.

The turning point in the retrofit struggle came from the engineering research community. Frieder Seible, one of the UCSD engineers who played a major role in Caltrans research and peer review panels, was on the peer review panel for the Coronado Bridge retrofit. Realizing that their relationship with the community was on shaky ground, local Caltrans officials approached Seible to discuss the technical issues with community leaders. Seible brought the activists to UCSD to tour the structural engineering laboratory there, where he explained the reasons for the retrofit and showed them large-scale test specimens of bridge columns that had been put through simulated earthquakes. This apparently made a significant impression on community leaders, and convinced many of the sceptics present that retrofit was actually needed (Sims 2000, p. 272).

Seible worked both sides of the problem, however. Using his position on the peer review panel, he pushed Caltrans to require a more detailed analysis of the overpass columns in the design process, including testing sample columns at the UCSD lab. When this analysis was completed, and with new data on soils at the site, the designers concluded that retrofitting work could be limited to only the footings of the columns. In other words, almost all the work could be done below the existing ground level, sparing the murals (Sims 2000, pp. 272–273).

The events surrounding the Coronado bridge retrofit created a local extension of the Caltrans bridge engineering network that included columns as risk objects in two ways: as structures that could collapse in earthquakes, and as structures bearing murals that were at risk of damage in the retrofit process. Key actors, practices, and objects from the larger, systemic Caltrans retrofit program were redeployed within this local network, most notably university researchers, with their technical knowledge and status as experts, and the laboratories and test specimens they controlled. In addition, a host of local actors became involved, including community groups, politicians, and locally-based Caltrans environmental planners. The result was a localized network that was more closely adapted to local circumstances surrounding one particular retrofit

project. This ultimately enabled that local project to proceed, contributing in a small way to the larger, systemic retrofit effort.

The story of Chicano Park and the Coronado Bridge retrofit also shows that urban retrofit projects can involve much more in the way of conflict and adversarial power relations than the comparatively consensus-drive process that characterized the Caltrans retrofit program at a systemic level. Actors who lack political voice may be marginalized and made invisible. Slippage may be driven not by gradual drift in technical standards over time, but by new actors forcibly inserting themselves into existing networks of power and vehemently disagreeing with the status quo. These highly charged political and cultural meanings can invest sociotechnical networks with yet another localized layer of complexity that engineers and planners must account for in the retrofit design process.

Conclusion

The Caltrans seismic retrofit program is a story of heterogeneous engineering (Law 1987), in which a group of engineers put together a network of ever-increasing complexity that enabled them to sustain a retrofit program amid a variety of local and global contingencies with the potential to destabilize it. To do so, they articulated key slippages between bridge structures as they existed, and bridge structures as they ought to be to prevent loss of life in earthquakes, according to changing engineering standards. In doing so, they positioned themselves as retrofit experts and maintained control over their engineering practices through a period of rapid technological change. However, the Coronado bridge case also drives home the fact that it is not only engineers who engage in heterogeneous engineering and retrofit; activists and community groups can push their own agendas for urban renewal, which intersect and play off of engineers' efforts in interesting and complex ways. The overall view that emerges is that retrofit, like other infrastructural projects, involves construction of networks of people, things, and practices that span a wide range of scales and locales. Retrofit is especially complex and difficult because new networks must integrate particularly closely with already established networks, greatly constraining what can be done. Resolution of these tensions and constraints is what makes a successful retrofit program possible.

Non-systemic retrofit is a ubiquitous feature of urban environments: governments, property owners, and communities are constantly repairing, remodelling, expanding, and adapting elements of the built environment to fit evolving local and global needs. Over time, these changes may create a local equilibrium that reflects the negotiation and settlement of a variety of political, economic, and cultural interests. Systemic retrofit programs often reflect the agendas of global professional, business, and political groups, and are usually planned at a regional or national level where it is difficult to take these myriad localized settlements into account. This was certainly the case with the Caltrans seismic retrofit program, which initially took shape through a complex series of interactions between engineers, legislators, the governor, and state and national media. As a result, at the point of local implementation, these programs may

threaten to disrupt established power relations, possibly putting groups included in existing settlements on the defensive, or providing an opening for previously excluded groups to assert their interests.

This can create a delicate balancing act for local retrofit planners and engineers, who must weigh technical and cost requirements against the potential for antagonizing political and economic interests. As a result of more inclusive urban development policies since the 1960s, they may also be constrained by laws and ethical standards that require sensitivity to the interests of relevant local stakeholders, including those who have been excluded in the past. In the Coronado Bridge retrofit case, managing these issues required the involvement of Caltrans historians and bridge engineers at the state level, local Caltrans engineers and environmental planners, academic researchers, and political and community leaders, all of whom had different degrees of engineering knowledge, scope of understanding of local needs and interests, and levels of credibility within Caltrans and the local community.

Of course, there are many retrofit programs that will not encounter this kind of local complexity so acutely, possibly because the proposed retrofits are less visible, have less impact on culturally meaningful structures, or simply don't mobilize any local opposition. Alternatively, cultural and political complexities may be ignored or discounted because a decision has been made at the systemic level that the need for retrofit of a certain form outweighs local concerns. Even though it may not be representative of all systemic retrofit programs, the Caltrans seismic retrofit program provides useful illustrations of the possible complexities that may emerge in less dramatic form even in more routine retrofit projects.

Systemic retrofit, like any kind of infrastructure engineering, is a thoroughly sociotechnical problem, requiring adaptation to both global and localized cultural and material constraints. In urban environments, balancing these constraints becomes particularly complex due to the dense local layerings and interpenetrations of social, cultural, and technological networks. Retrofit can open up latent tensions within and between local networks, generating controversy and conflict that can threaten to derail the engineering process. Systemic retrofit programs are typically developed within a larger global network, where they may be shaped by very different sets of constraints than are encountered at the local level. As a result, they may initially be insensitive to local contingencies. Where these tensions become acute, managing them is critical to maintaining a sustainable and socially responsive systemic retrofit program.

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¹ Elements of this chapter are drawn from the author's PhD dissertation, *On Shifting Ground: Earthquakes, Retrofit, and Engineering Culture in California* (Sims 2000). Many of the specific details regarding Caltrans activities are drawn from interviews with engineering researchers and Caltrans engineers, planners and consultants conducted between 1996 and 1998, and from documents in Caltrans internal archives. Detailed notes regarding sources for specific observations and events can be found in the referenced pages of the dissertation.

² Our definition of repair draws on both its colloquial meaning of fixing broken machinery, and its use in the field of ethnomethodology, where it describes how people restore conversational order and meaning following breakdowns or misunderstandings (Schegloff *et al.* 1977). We expand these uses of repair to encompass larger-scale efforts to restore order at a systemic level.