# 미국 Kingdome 구조물 발파해체사례

## The Kingdome Implosion

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본 기사는 2000년 3월 26일 미국 시애틀 소재 Kingdome 체육관 시설을 발파해체공법을 이용하여 해체한 사례로서 The Journal of Explosives Engineering(v.17 n.5, 2000)에 기고한 Dr. Douglas A. Anderson (Senior Consultant, West Chester, PA office of Schnabel Engineering Associates, Inc.)의 글을 옮긴 것이다. Kingdome 구조물의 해체와 해체 후 Seahawk Stadium 건설의 책임을 맡은 주계약자는 Turner Construction 회사이며 발파해체 사전준비 및 사후처리의 책임은 Aman Environment사, 발파해체 설계 및 시공은 CDI사, 주위 주요 구조물에 대한 영향평가 및 진동계측은 Schnabel Engineering Associates사가 맡아 수행하였다. 이 건물은 세계에서 가장 큰 규모의 쉘 콘크리트 돔 구조로 되어 있으며, 주위에 주요 구조물들이 위치하고 있고 특히 이 지역에 과거 발생했던 지진으로 인하여 주민들이 지반진동에 대한 피해나 또는 지진을 유발할 수도 있다는 위험 가능성에 매우 예민하여 관심이 높았던 해체사례이다. 이 구조물을 한번에 붕괴시킬 경우 지반에 25,000톤의 중량이 충격으로 작용할 수 있으므로 충격을 최소화하기 위한 방법에 초점을 맞추어 설계되었으며 5,905개의 천공에 4,728파운드(약 2,145kg)의 폭약이 사용되었고 도폭선을 이용하여 기폭시켰다. 사용된 도폭선의 길이는 약 37.9 km에 달하였다. 발파해체작업은 기사에 나타나 있듯이 주위에 피해를 주지 않고 성공적으로 수행되었다.

### *Introduction*

Even though there is always a feeling of anticipation before a blast is detonated, most blasts are part of a day's work. Once in a while there is an event that impresses even the most jaded blaster.

Few blasts have had the impact of the Kingdome implosion in March of this year. Fortunately for both the Seattle area and the explosives community, the "impact" of the implosion was far less than many local residents had feared. This outcome, of course, was not by chance, but the result of careful planning and design. An urban implosion requires a mix of engineering, logistics, and public relations. Unique challenges on this project tested the resourcefulness of the entire team.

### *The Team*

Turner Construction is the prime contractor responsible for the removal of the Kingdome and the construction of the new Seahawk Stadium on the Kingdome footprint. Aman Environmental is responsible for the preparation of the Kingdome for implosion and the post-implosion cleanup. Controlled Demolition, Inc. (CDI) was responsible for the design and execution of the implosion. Schnabel Engineering Associates (Schnabel) and Skilling, Ward, Magnuson, and Barkshire (Skilling) teamed to conduct the pre- and post-implosion surveys of surrounding structures, and vibration monitoring at those structures. Schnabel developed vibration prediction based upon historical implosion vibration records.

### *The structure*

Like a Coliseum with a lid, the Kingdome was the world's largest thin-shell concrete dome structure. Built in 1974 at a cost of $67M (a slim budget for such a facility), it was designed by Jack Christiansen of Skilling to last a thousand years. The most notable feature was the unsupported roof structure. This roof was thin but strong, a hyperbolic paraboloid 660 feet across, In place of vertical supports, it had a tension ring at the outer perimeter, and a compression ring at the top. The largest remaining unsupported roof is that of the Assembly Hall at the University of Illinois. A smaller version sof the Kingdome, also designed by Jak Christiansen, is the SunDome in Yakima, Washington, which is going to remain standing.

Support of the Kingdome roof required very strong supporting columns, which contained Number 18 reinforcing rebar, the largest available, This rebar, which as thick as a soda can, bent like spaghetti during the implosion. The building was plagued during its lifespan by difficulties including falling of roof tiles, and a city that hated how it looked. Repairs to the building cost $74M, and though it is gone, it won't be paid for until 2016!

Why did it go? In modern sports, multipurpose stadiums like the Kingdome are now like dinosaurs. Skyboxes and moving ramps, which were not part of the Kingdome design, are now considered necessary. The new Seattle ballpark, Safeco Field to the south of the Kingdome footprint, fits the times better, as will the Seahawk Stadium. Finally, as usually is the case, a critical factor was money.

So it had to go. A dome isn't taken down piece by piece, so it had to come down at once. But what does "at once" mean, and what impact does it have? Let's start with the city around the dome.

### *The Surroundings*

The Kingdome was less hemmed in than some imploded buildings; however it was still surrounded on all sides by urban structures. On the south, support structures for the Seahawk Stadium had been erected within 100 feet at the time of the implosion. To the east, the busy Amtrak Pacific Coast railroad tracks and station were again within 100 feet. To the west, several industrial buildings, including historic structures, were also within 100 feet. Each of the foundations is on fill including timber, bricks and other poorly consolidated material. Elevated highways to the west of the Kingdome site were also of concern. A high-priced condominium complex to the northwest required special attention because of the cost of the units. North of the Kingdome site is the southern edge of downtown Seattle, with historic structures such as the King Street Station in full view of the Kingdome. finally, as in most urban areas, underground utilities, such as gas lines and fiber optic cables, were buried within 100 feet of the footprint.

All of these structures were of concern to the Seattle community. Furthermore, with the Seattle area subject to earthquakes, the residents were highly aware of the potential of ground vibration to cause damage. Some people were concerned that implosion vibrations might trigger an earthquake or liquefaction would destabilize building foundations. There were also concerns about dust and debris that would be generated by the implosion, the fate of pigeons and stray cats, and mobilization of rats.

To allay these fears Schnabel generated predictive vibration models, based upon the results of previous implosions. These models, using the weight and fall time of the Kingdome, indicated that vibration would be well below levels that could cause cosmetic damage.

### *The Media*

The media attention to this implosion was intense. The local media featured the implosion daily with stories about the implications of the implosion. National coverage by MSNBC and ESPN added to the spirit of carnival. Websites showed the progress of preparations and "models" of the implosion.

Unfortunately, some negative press coverage was generated by competitors. These actions however, were not taken seriously enough to interfere with the positive media coverage prompted by the event.

### *Preparation*

Well before the implosion, preparations were underway An environmental impact statement was completed in early 1998, with estimates of potential vibration magnitude and other impacts to the Seattle area. Coordination was made through the Seattle Fire Marshal's office. Local agencies were contacted, as were residents, to inform people of the possible impact and measures to be taken to minimize adverse effects.

Along with organizational efforts, a monitoring plan was developed, as well as coordination of pre-implosion surveys. Interior and exterior videotaping and other inspection services were conducted on the buildings surrounding the Kingdome. Secure areas were defined. Plans for interrupting rail and vehicular traffic were developed.

### *Design*

How do you take down a dome? Most implosions fall into one of two categories: either critical support is removed in a well-defined sequence allowing a building to pancake and crumble, or it is toppled like a tree (gas towers and chimneys). Simply pancaking a dome would create too much vibration, with 25,000 tons of material impacting the ground at once.

CDI designed an implosion detonation sequence that would allow the building to fall in a manner similar to conventional building implosions. The dome roof was divided into six sectors - similar to the familiar radioactivity symbol - that would be imploded in two sequential phases.

Envision six men standing in a circle, arms on each other's shoulders, like a huddle. Three of the men (non-adjacent) are knocked out, and fall inward, still supported by the remaining three. Then the last three are knocked out and are dragged into the middle by the weight of the first three. They all end up in a pile in the middle. We won't carry the analogy too far, but this is how the sequence proceeded, with selective weakening of critical elements (precise breaking of the structure's "legs"). This was to prevent all material (but dust) from leaving the footprint, and allowing the roof to crumple rather than crash. Berms made of crushed concrete of the lower stadium levels were also placed on the floor of the Kingdome to help absorb the impact.

### *Test Blast*

As is usually the case with substantial implosion projects, a test blast was detonated about a week before the implosion. Columns could be weakened with smaller quantities of explosives than originally estimated. This would help in scattering less debris and lowering the resultant air overpressure.

### *Loading*

Drilling of the 5,905 holes in the structure for explosive charges took fine weeks. These holes were loaded with a total of 4728 pounds of explosive, wrapped with mesh, and hooked up with 21.6 miles of detonating cord. The loaded areas were covered with geotextile material to contain the debris from the detonation.

### *Monitoring*

The implosion was monitored with 17 Instanter seismographs provided by Schnabel Engineering. These were placed at Locations of concern for liability protection, as shown in the Location Plan. They were coupled to the pavement with bolted metal plates where coupling directly to the soil was not available Since the fall time of the Kingdome was estimated to be about 17 seconds, the seismographs were programmed to record for 30 seconds when triggered. Because of the possibility of false triggers filling the memory, the seismographs were set to turn on automatically 30 minutes before the implosion.

In addition, a 25-person team from the US Geological Survey and the University of Washington deployed 200 seismographs throughout the city to determine the wave propagation characteristics in the Seattle area. The vibration generated by the impact could aid the geophysical community in predicting local response to ground vibration. These studies are part of the Seismic Hazards in Puget Sound or "SHIPS" program to estimate earthquake response potential in the Seattle area.

### *The Implosion*

The morning of March 26 was atypical for Seattle - only a few clouds were scattered in a bright sky, and fog burned off early. While it was still dark, at 5 AM, seismographs were set up, and final detonator hookup was finished. The area around the Kingdome was cleared of all but those with the appropriate badges. Coordination activities were in a large tent "Command Post" filled with people from various city agencies and the demolition team.

Outside, helicopters circled overhead. The crowds gathered at the barriers, many prepared with masks for the expected dust. Ships filled the harbor, and high-rise breakfast parties waited in anticipation. Vendors hawked T-shirts and other souvenirs, but the souvenirs in most demand would be pieces of the Kingdome. With over 100,000 tons of material, there would be plenty to go around!

At 8:30 AM the final siren sounded, and at 8:32 the detonation sequence began. The rapid-fire concussion from the detonating cord could be felt at the command post as the building began to crumple. Shortly into the 17-second sequence, the billowing dust began to rise above the falling building.

The dust cloud turned the clear day into twilight. Just as the last of the Kingdome crumpled, the command post became a bustle of activity to assess the conditions following the implosion. Before anyone could return to the site, seismograph readings had to be taken to determine how much vibration had been generated. Two seismic records with peak particle velocities of 0.24 and 0.25 at the northern edge of the Kingdome site indicated that all was safe for people to return to the site.

### *Results*

Five windows broken, a lot of dust, and thousands of cheering people. Oh, yes, and a Kingdome flattened like a pressed flower. The planned sequence had worked like a charm. The anticipated height of the final rubble pile was (by contract) supposed to be less than 70 feet, but ended up only 23 feet high. The flagpole on the center of the compression ring remained more or less vertical. The vibration predictions were right on.

High-five were exchanged quickly, and the work of assessing the impact began almost immediately. The seismographs were collected, and post-implosion inspections began. As the dust cleared, it was evident that the several approaches - engineering, logistical, and public relations - had all worked in concert to provide a valuable service to the clients and the community. The dismantling of what remained began while there was still dust in the air. The new stadium is now under construction.

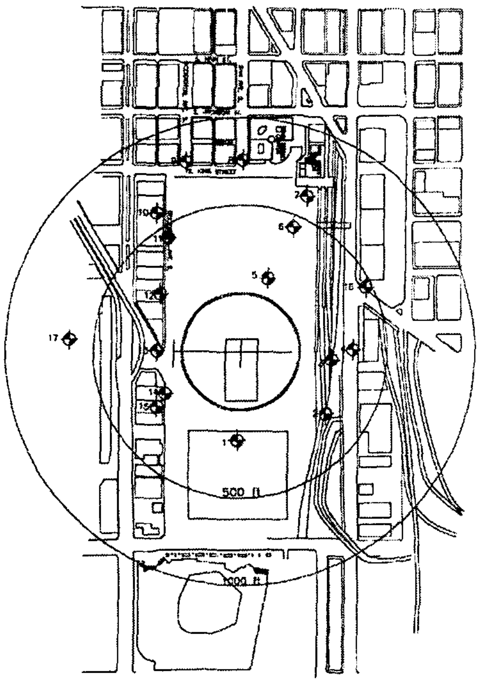
After all, with the excitement over, Mark Loizeaux of CDI probably summed up the feelings of an explosives professional best. Referring to the attitude of a football player in the endzone after a critical touchdown he said "Act like you've been there before.

▷ 관련사진

사진 1. 폭약 장전 및 부직포 설치

사진 2. 충격완화를 위해 바닥에 쌓은 소단들의 모습


사진 3. Kingdom 구조물과 진동측정계를 설치하는 모습




Seismograph Location Plan.

사진 4. 진동측정기 설치 위치도


사진 5. 균열이 발생해 있는 벽의 영향을
조사하기 위한 crack gage와 진동측정기

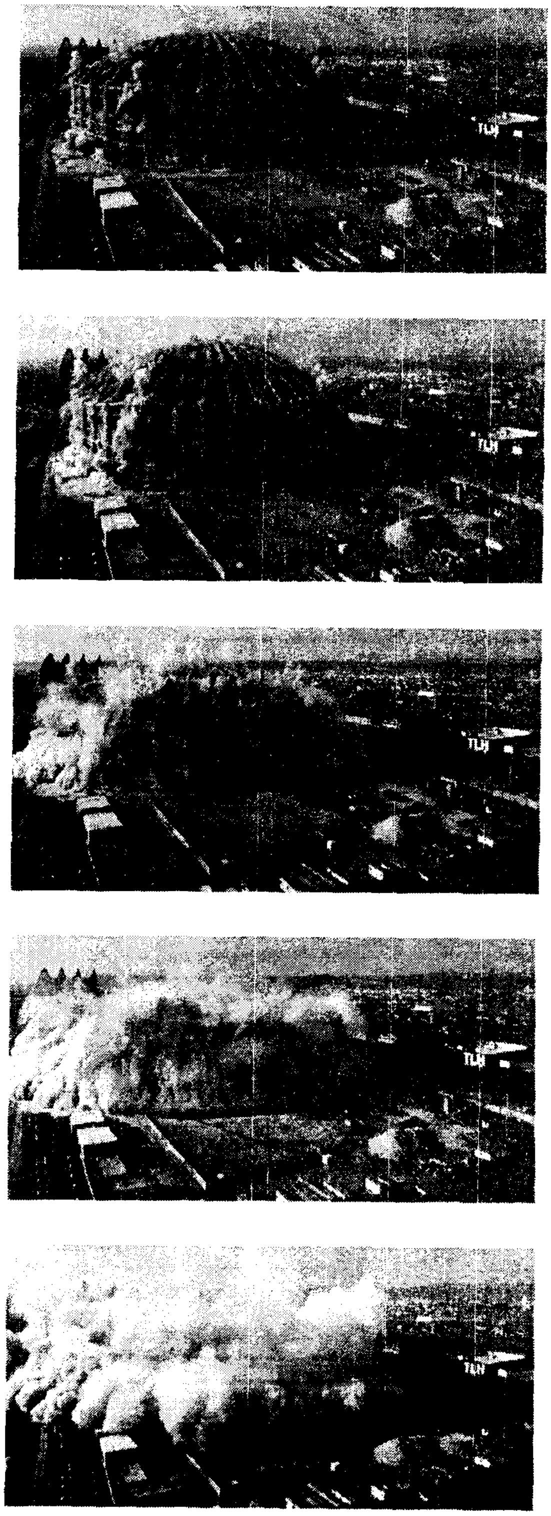


사진 6. 발파해체 과정

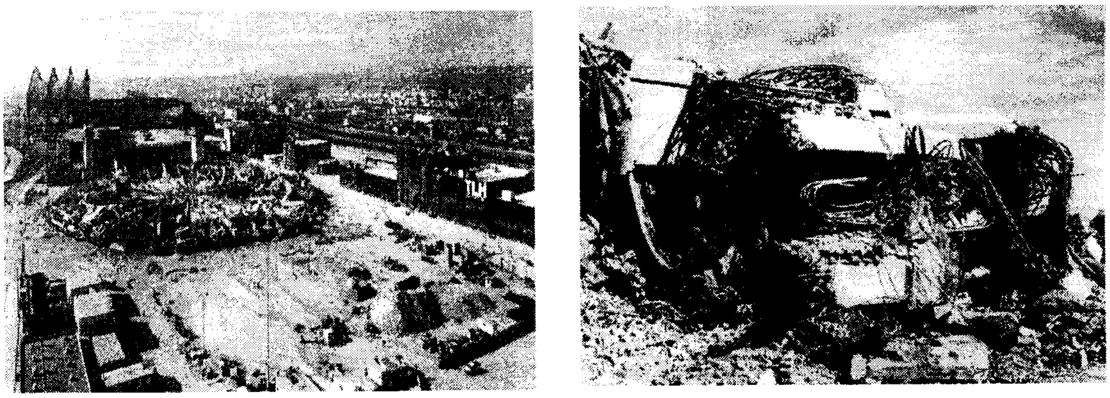


사진 7. 해체후 모습

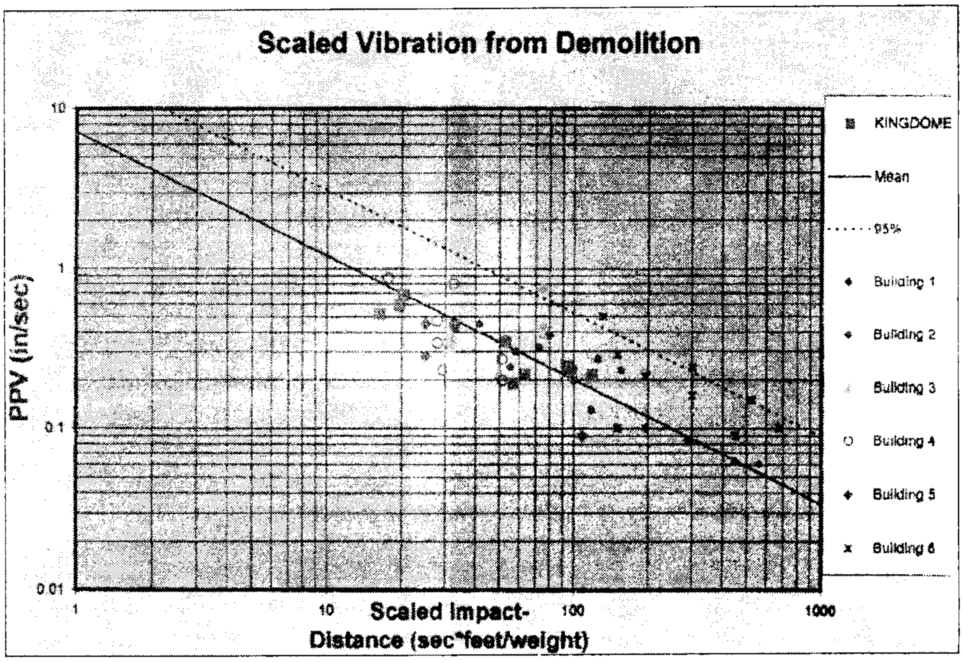



사진 8. 발파해체시 계측된 진동의 수준