INSTRUMENTATION REQUIREMENTS FOR TALL BUILDINGS PER THE LOS ANGELES TALL BUILDINGS STRUCTURAL DESIGN COUNCIL 2011 ALTERNATIVE ANALYSIS AND DESIGN PROCEDURE

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Abstract

Seismic instrumentation can provide valuable insight into performance of structures and help us assess the validity, or lack thereof, of assumptions used and methods applied. It is precisely for this reason that the Los Angeles Tall Building Structural Design Council (LATBSDC) mandates extensive seismic instrumentation of tall buildings designed according to the provisions of its alternative analysis and design procedure that has been adopted by the Department of Building and Safety of the city of Los Angeles. This paper describes 2011 LATBSDC seismic instrumentation requirements and provides an example of their application.

Introduction

Performance based design of tall buildings is in its early stages of application and development. The funding necessary to experimentally validate performance of various components and systems utilized in tall buildings probably will not be available for a long time. Analytical simulations, as detailed and elaborate as they may be, cannot replace the need for experimental results and observed performances. It is imperative that we maximize every opportunity at our disposal to learn as much we can and as quickly as possible about performance of tall buildings designed according to these procedures during major earthquakes so that we can improve our design practices and produce more efficient and safe buildings.

Seismic instrumentation can provide valuable insight into performance of structures and help us assess the validity, or lack thereof, of assumptions used and methods applied. It is precisely for this reason that the 2011 LATBSDC mandates extensive seismic instrumentation of tall buildings designed according to its provisions.

A Brief History of the LATBSDC Document

LATBSDC was formed was formed in 1988 to provide a forum for the discussion of issues relating to the design of tall buildings. The Council seeks to advance state-of-the-art structural design through interaction with other professional organizations, building departments, and university researchers as well as recognize significant contributions to the structural design of tall buildings. LATBSDC is a nonprofit California corporation whose members are those individuals who have demonstrated exceptional professional accomplishments in the structural design of tall buildings. The annual meeting of the Council represents a program for engineers, architects, contractors, building Official and students. The annual meeting program includes research reports on areas of emerging importance, case studies of current structural designs, and consensus documents by the membership on contemporary design issues. LATBSDC criteria documents are published under a unanimous consent requirement, which makes publication of them laborious process.

The first criteria document published by LATBSDC in the late 1980s covered the topic of application of site-specific design spectra and dynamic analysis, which were hot topics during that time. The first performance-based alternative analysis and design criteria document was published in 2005 and has been since updated every three years. The current document is the 2011 edition. Every edition of LATBSDC has contained mandatory extensive instrumentation requirements.

Why a Document on Tall Buildings?

A tall building represents a significant investment of human and material resources and may be occupied by hundreds, if not thousands, of occupants. Building codes' reaction to this fact, at least in the United States, has been twofold. First, application of certain structural systems has been limited to certain heights and second, buildings with high occupancy are required to be designed for higher lateral forces via the use of an importance factor (I) which is taken as unity for ordinary buildings. Numerous studies and evaluations [1, 2, 3] have shown that it is possible and economical to design tall buildings as safe or safer than code designed buildings while ignoring code imposed height limits. Furthermore, even a strict imposition of arbitrary premiums on elastic design forces may not do much to address the issues of damage and potential collapse, which are inherently inelastic and nonlinear.

Prescriptive codes by in large contain a collection of empirical rules and experimental results that have evolved over many years of practice and in a sense provide a "one size fits all" approach to seismic design. Tall buildings as small class of specialized structures will perform better during earthquakes if special attention is afforded to their individual seismic behavior and engineers are provided with ample opportunities to explore new frontiers, utilize state of the art technologies and latest research results in order to improve the performance, feasibility, and constructability of their designs.

There are other reasons why performance-based design of tall buildings and production of documents to guide such design has gathered momentum [4]. The overwhelming majority of construction in United States and worldwide consists of low-rise buildings. According to Portland Cement Association [5], buildings with one to three floors represent 93% of floor area of construction in United States while buildings with 14 floors or more represent only 1% of floor area of construction. With so much of the construction effort concentrated on low-rise construction it is not surprising that the code writers have these buildings in mind when crafting code provisions. As a result, one can often find a provision or two in the building code that either do not have relevance to tall building design, or even worse, do not make much sense for design of tall buildings. For example, until just a few years ago, the Los Angeles Building Code had a very peculiar drift design provision [6] requiring story drift not to exceed $0.020/T^{1/3}$ where T is the fundamental vibration period of the building. This provision, which was later retracted, probably did not have a serious effect on design of low-rise buildings but was a huge straightjacket for design of tall buildings with long vibration periods.

LATBSDC was the first professional group in the United States to publish a performance-based alternative seismic analysis and design criteria specifically intended for tall buildings [7, 8, 9] and to obtain approval by the city's building officials in 2010 for its use in lieu of using prescriptive code provisions for buildings of all types and heights.

LATBSDC Building Performance Objectives

The 2011 edition of LATBSDC criteria [9] sets two performance objectives: (1) serviceable behavior when subjected to frequent earthquakes defined as events having a 50% probability of being exceeded in 30 years (43 year return period); and (2) a low probability of collapse under extremely rare earthquakes defined as events having a 2% probability of being exceeded in 50 years (2,475 year return period) with a deterministic cap. This earthquake is the Maximum Considered Earthquake (MCE) as defined by ASCE 7-05 [10].

LATBSDC Instrumentation Requirements

2011 LATBSDC seismic instrumentation requirements are contained in Section 5 of that document which states: buildings analyzed and designed according to the provisions of this document shall be furnished with seismic instrumentation as described therein.

Instrumentation Objectives

The primary objective of structural monitoring is to improve safety and reliability of building systems by providing data to improve computer modeling and enable damage detection for post-event condition assessment. Given the spectrum of structural systems used and response quantities of interest (acceleration, displacement, strain, rotation, pressure), the goal of these provisions is to provide practical and flexible requirements for instrumentation to facilitate achieving these broad objectives. The instrumentation used on a given building should be selected to provide the most useful data for post-event condition assessment." It further states that the "recent advances in real-time structural health monitoring and near real-time damage detection may be extremely useful in rapid evaluation of status of the building after an event and deciding whether the building is fit for continued occupancy or not" [11].

Instrumentation Plan and Review

An instrumentation plan shall be prepared by the EOR and submitted to SPRP and Building Official for review and approval. SPRP Approved instrumentation plans shall be marked accordingly on the structural drawings. If the building is intended to be included in the inventory of buildings monitored by the California Geologic Survey (CGS) then the recorders and accelerometers must be of a type approved by CGS.

Minimum Number of Channels

The building shall be provided with minimum instrumentation as specified in the document (see Table 1 below). The minimum number of required channels maybe increased at the discretion of the peer review team and building officials. Please note that for reliable real-time structural health monitoring and performance evaluations a substantially larger number of channels may be necessary [11]. Each channel corresponds to a single response quantity of interest (e.g., unidirectional floor acceleration, interstory displacement, etc.).

Table 1. Minimum tall building instrumentation levels

Number of Stories Above Ground	Minimum Number of Sensors
10 – 20	15
20 – 30	21
30 – 50	24
> 50	30

Distribution

The distribution or layout of the proposed instrumentation shall be logically designed to monitor the most meaningful quantities. The sensors shall be located at key measurement locations in the building as appropriate for the measurement objectives and sensor types. The sensors shall be connected by dedicated cabling to one or more central recorders, interconnected for common time and triggering, located in an accessible, protected location with provision for communication.

Installation and Maintenance

The building owner shall install and maintain the instrumentation system and coordinate dissemination of data as necessary with the Building Official

Example Application

The instrumentation requirements of 2011 LATBSDC can be rather easily satisfied by development of simple instrumentation plans which are very similar to CSMIP produced sketches for its instrumented buildings. The owners and engineers of new tall buildings in Los Angeles region are often advised by their peer review panel to contact CSMIP for up to date information and relevant specifications and to enquire whether their instrumented building may become part of the CSMIP database of instrumented buildings.

Several tall buildings designed according to the provisions of the 2011 LATBSDC are in various stages of design and construction. The 34-story 888 Olive, which is currently under construction in downtown Los Angeles, is one example of such buildings. The lateral system for the tower consists of a core shear wall buildings. The tower sits on a podium on its lowest several floors some of which are subterranean and it is flanked by a seismically separated parking structure (Figure 1).

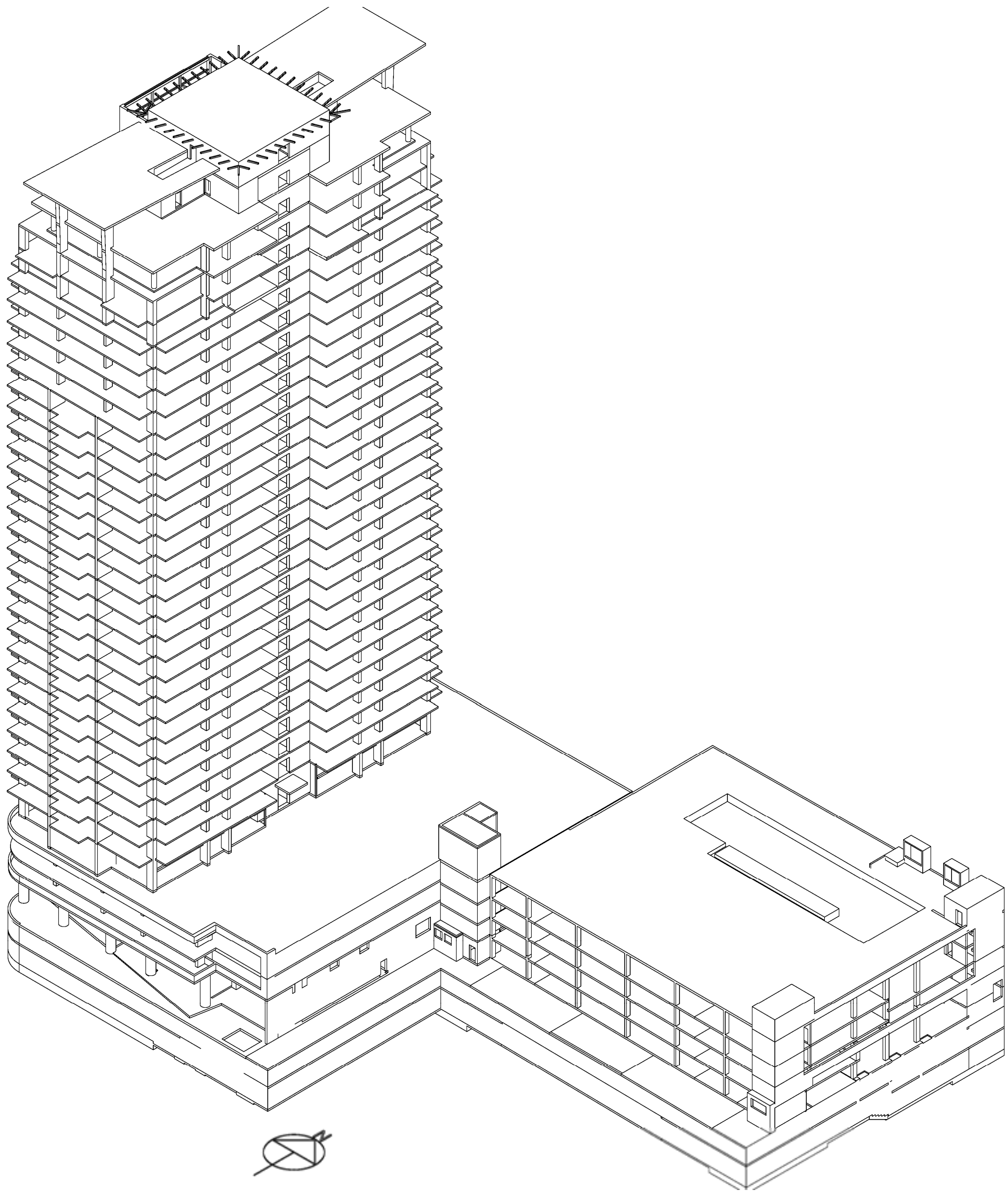

Figure 1. A 3D sketch of the 888 Olive Project with its tower, Podium and the adjacent parking structure (illustration courtesy of Glotman-Simpson and Onni Group).

The building is being instrumented with 24 accelerometers all connected to a central processing unit and once completed will become a part of SMIP database of instrumented buildings. The entire set of instrumentation plans produced for this project is presented in the Appendix of this paper.

Conclusions

Instrumentation is inexpensive and nonintrusive if planned during the design process and implemented during the construction of a tall building. Given the recent advances in sensor technology, now it is possible to install sensors not only to measure accelerations but to measure and record relative or overall displacements (building tilt), and various stresses and strains throughout the structure. Modern information technology has made real-time or near real-time measurements and remote transmission of sensor data and engineering interpretation of them not only possible, but feasible. Integration of seismic instrumentation with broad building health monitoring which includes monitoring buildings during more frequent events and malfunctions (such as wind storms, fires, floor vibrations, flooding, elevator functions, HVAC problems), may finally produce enough tangible benefits for tall building owners and developers to cause them to willingly and enthusiastically embrace the modest cost of building instrumentation and health monitoring.

Acknowledgment

The author is grateful to Onni Group (developers) and Glotman-Simpson (engineers of record) for the 888 S. Olive project for allowing the author to reproduce the schematic view of the building (Figure 1) and their instrumentation plans (Appendix) as a part of this paper.

References

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2. Los Angeles Tall Buildings Structural Design *Council, Proceedings of the 2008 Annual Meeting*, Los Angeles, California. May 2008.
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9. Los Angeles Tall Buildings Structural Design Council (LATBSDC), *An Alternative Procedure for Seismic Analysis and Design of Tall Buildings located in the Los Angeles Region*, 2011 Edition, May 2011.
10. American Society of Civil Engineers (2005), *ASCE 7-05 Minimum Design Loads for Buildings and Other Structures Including Supplement 1*, Reston, VA.
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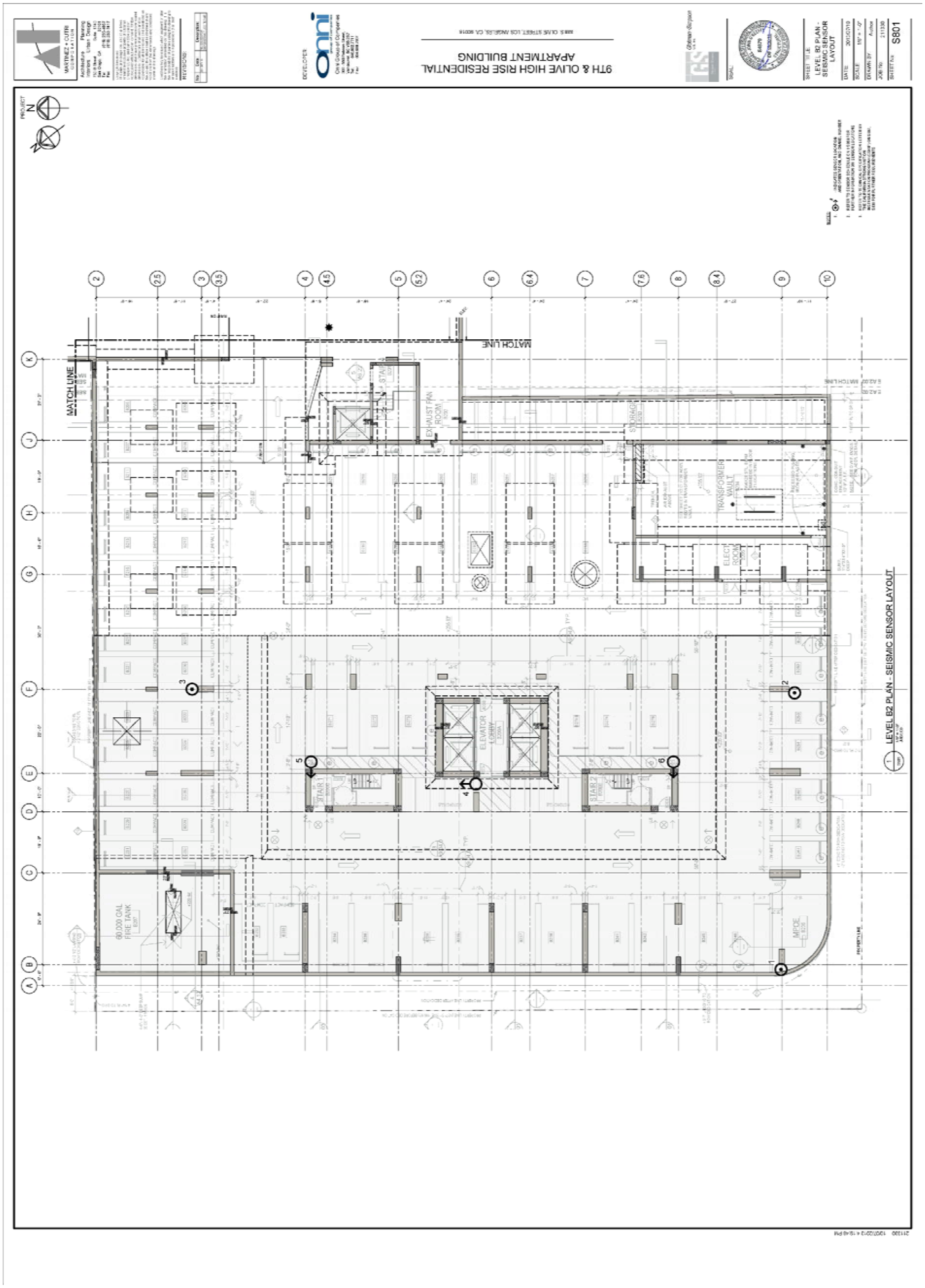
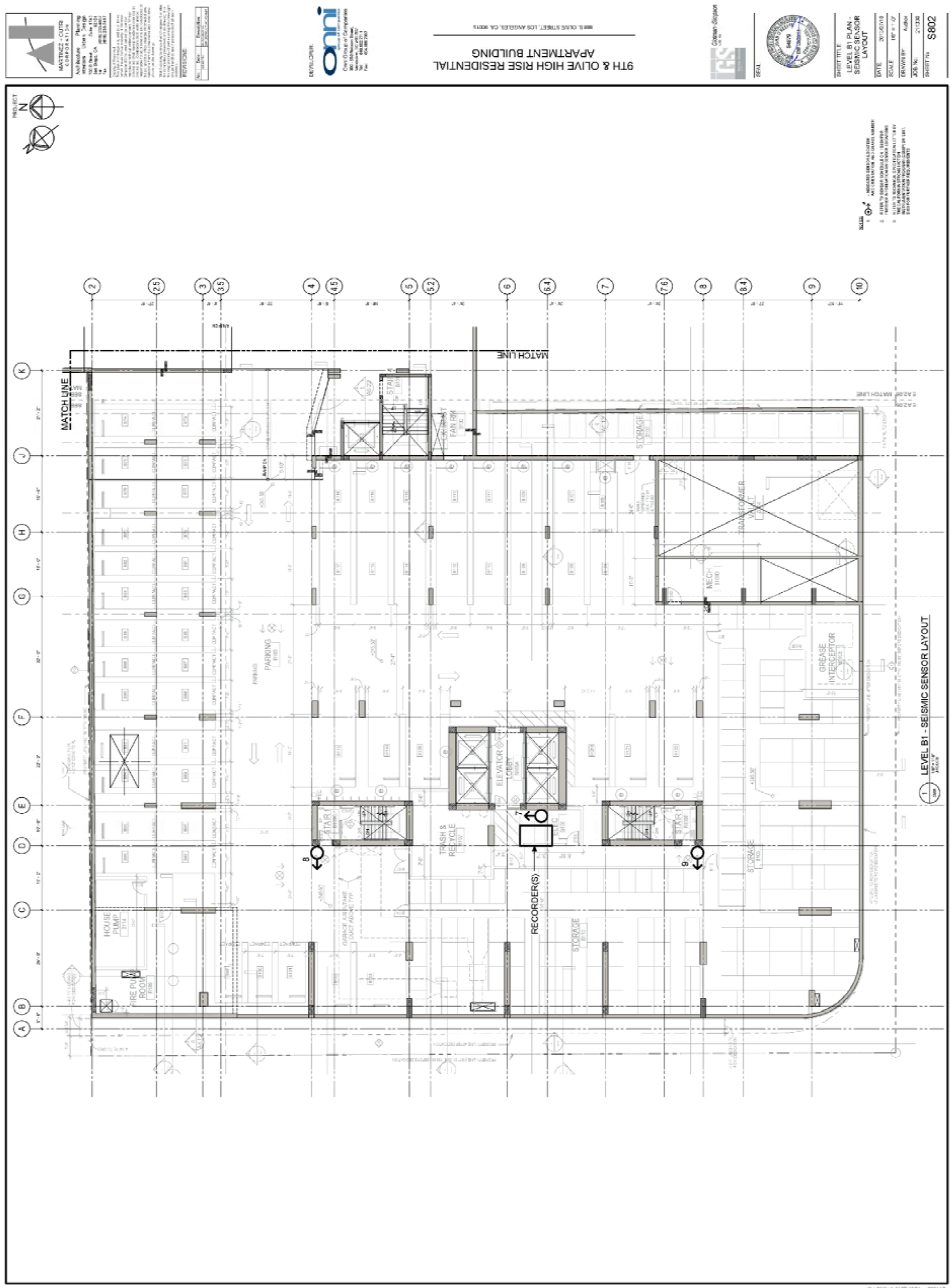
APPENDIX – Instrumentation Plans for 888 Olive Tower located in downtown Los Angeles


9TH & OLIVE HIGH RISE RESIDENTIAL
APARTMENT BUILDING
LEVEL B2 PLAN - SEISMIC SENSOR LAYOUT
S801
MATCH LINE
ELEVATOR LOBBY
STAIR 1
STAIR 2
60,000 GAL FIRE TANK
TRANSFORMER VAULT
EXHAUST FAN ROOM
STORAGE
MPOE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APARTMENT BUILDING
LEVEL B1 - SEISMIC SENSOR LAYOUT
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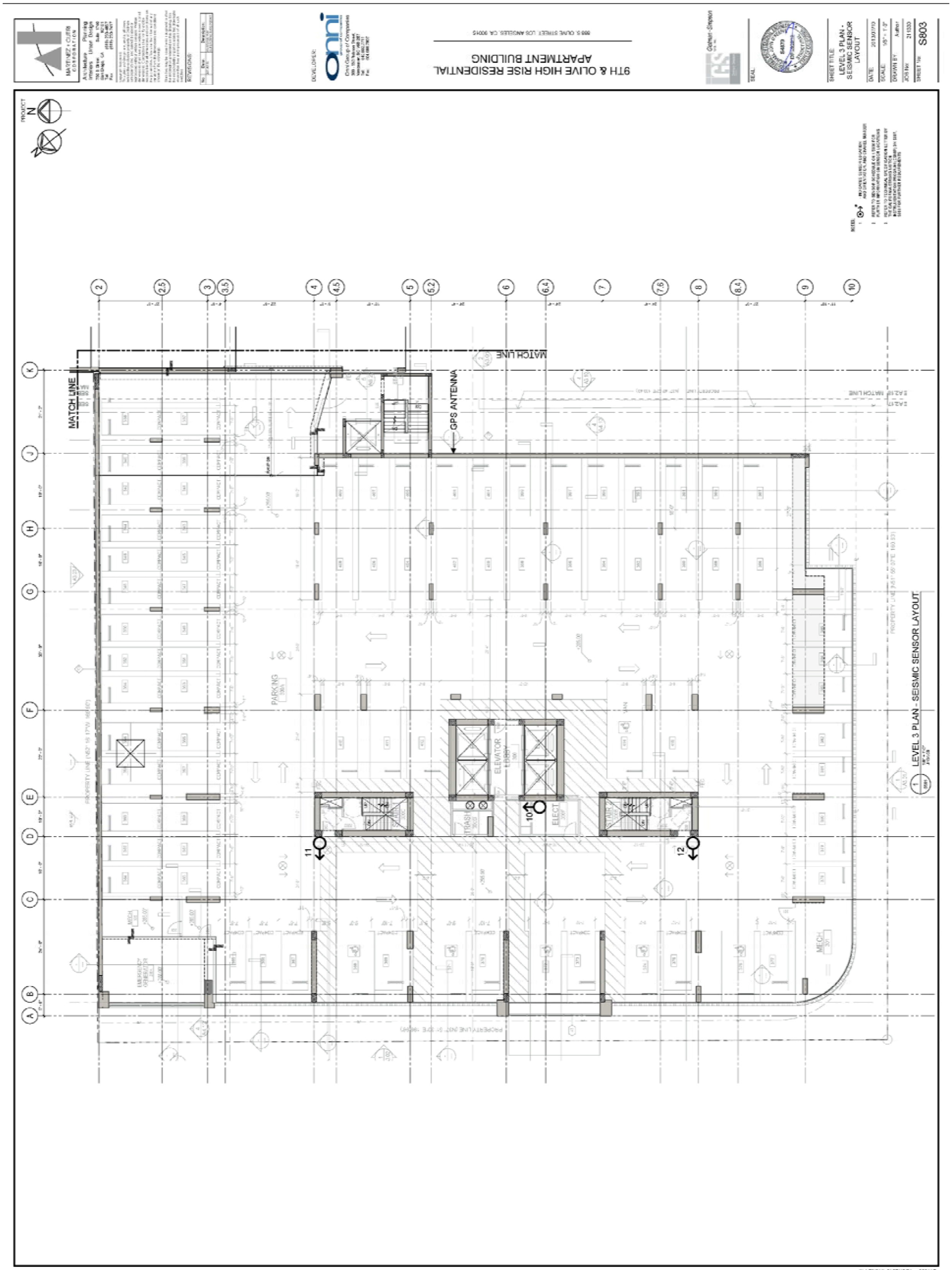
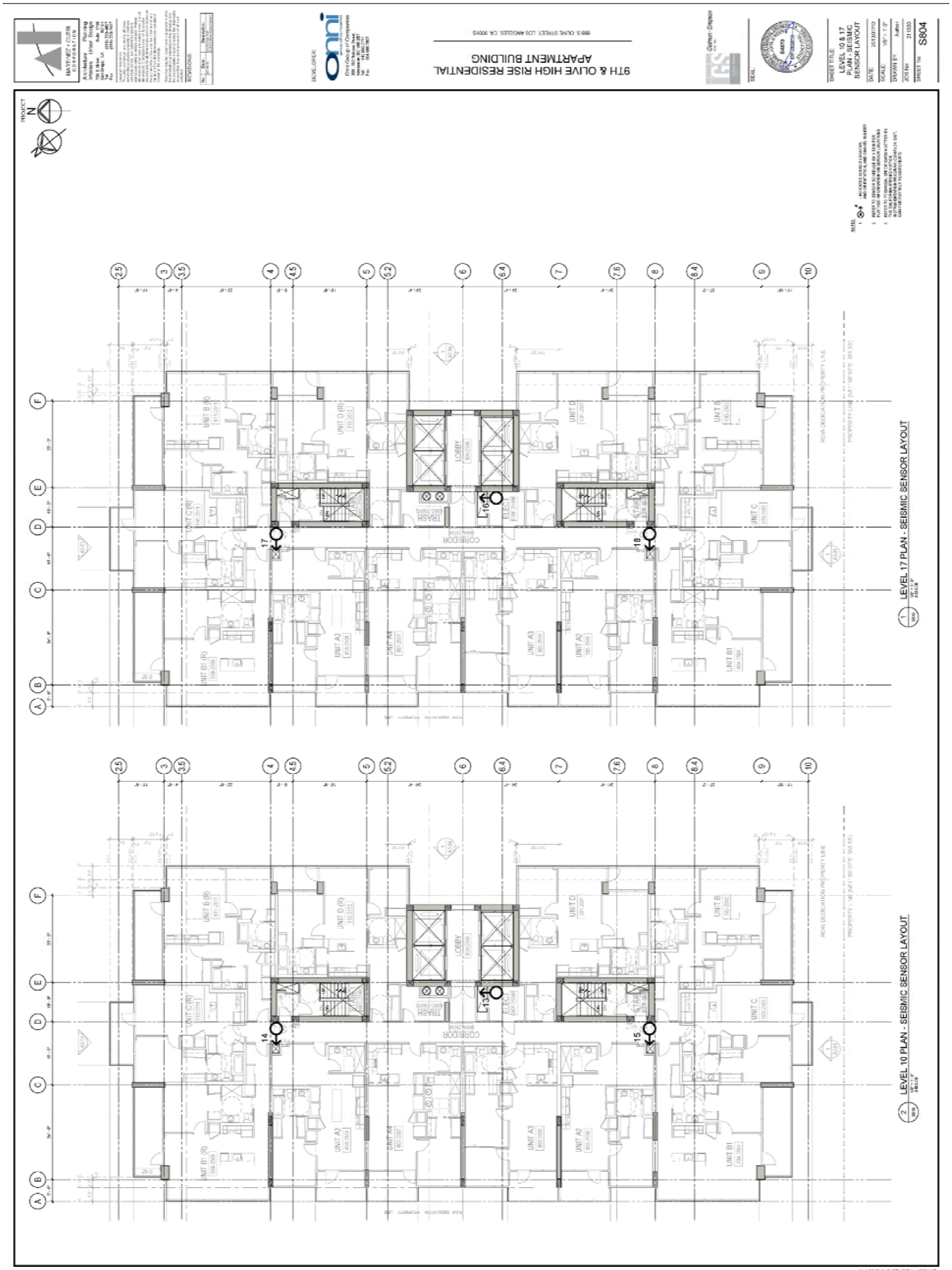
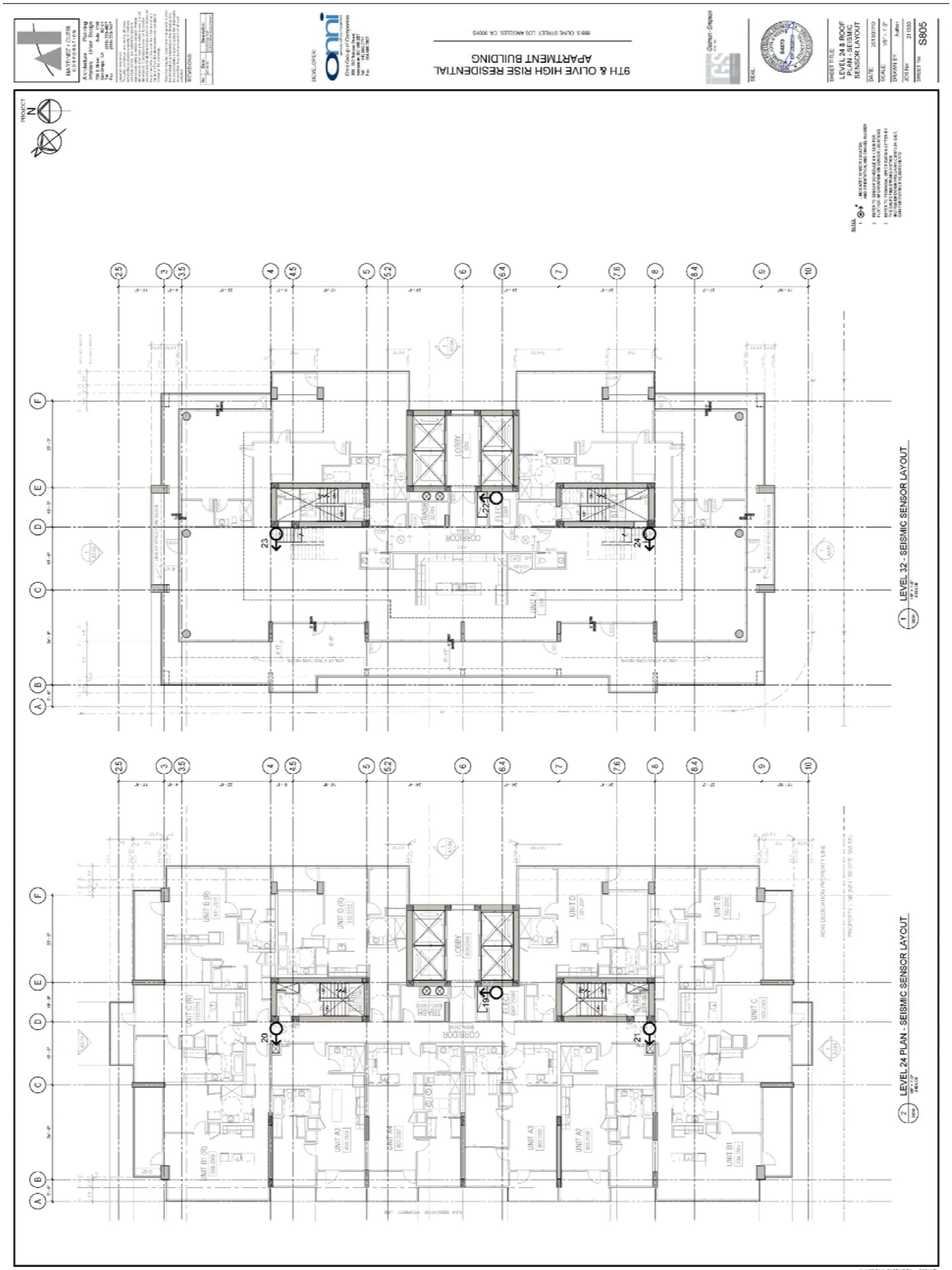
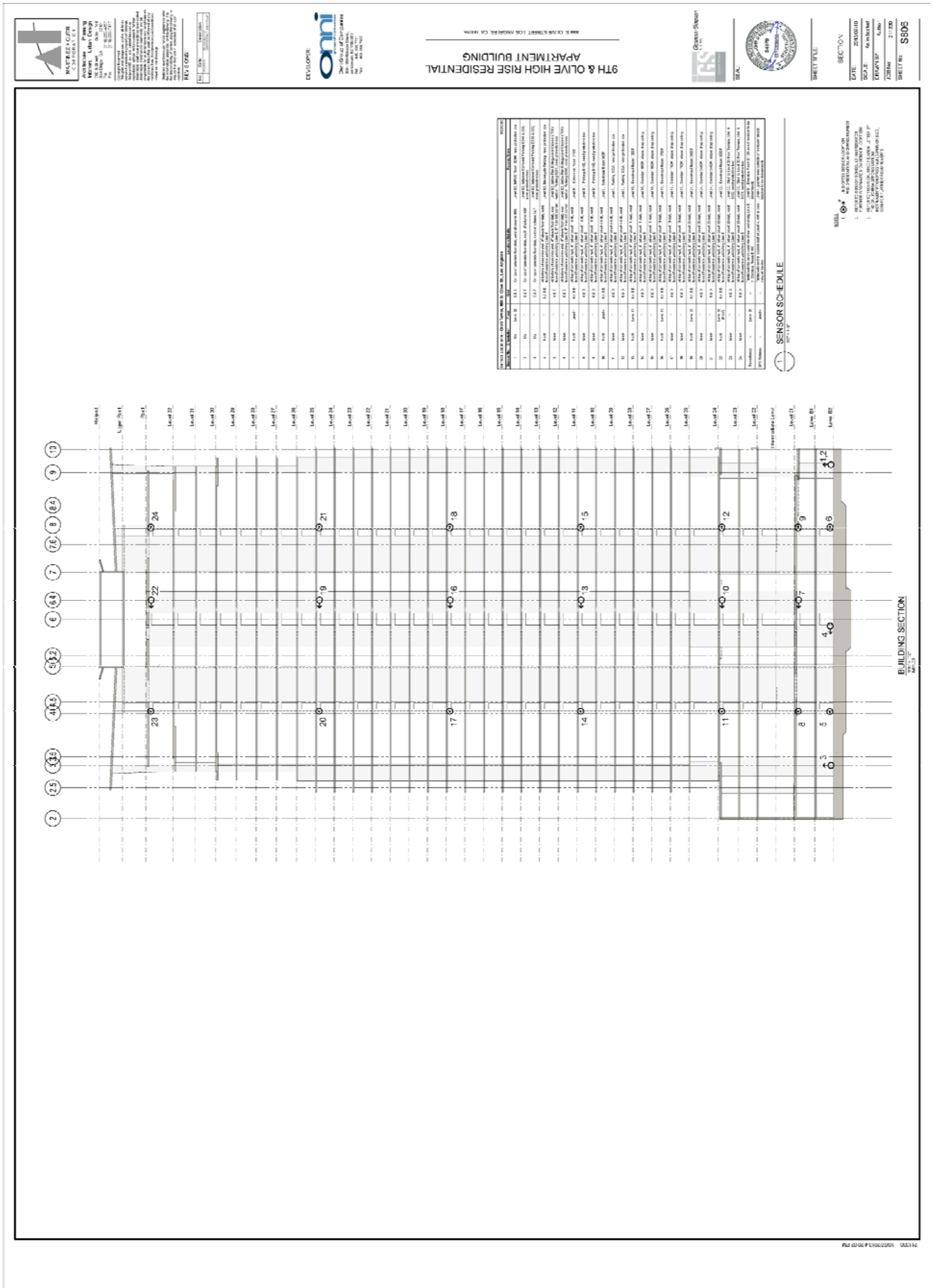
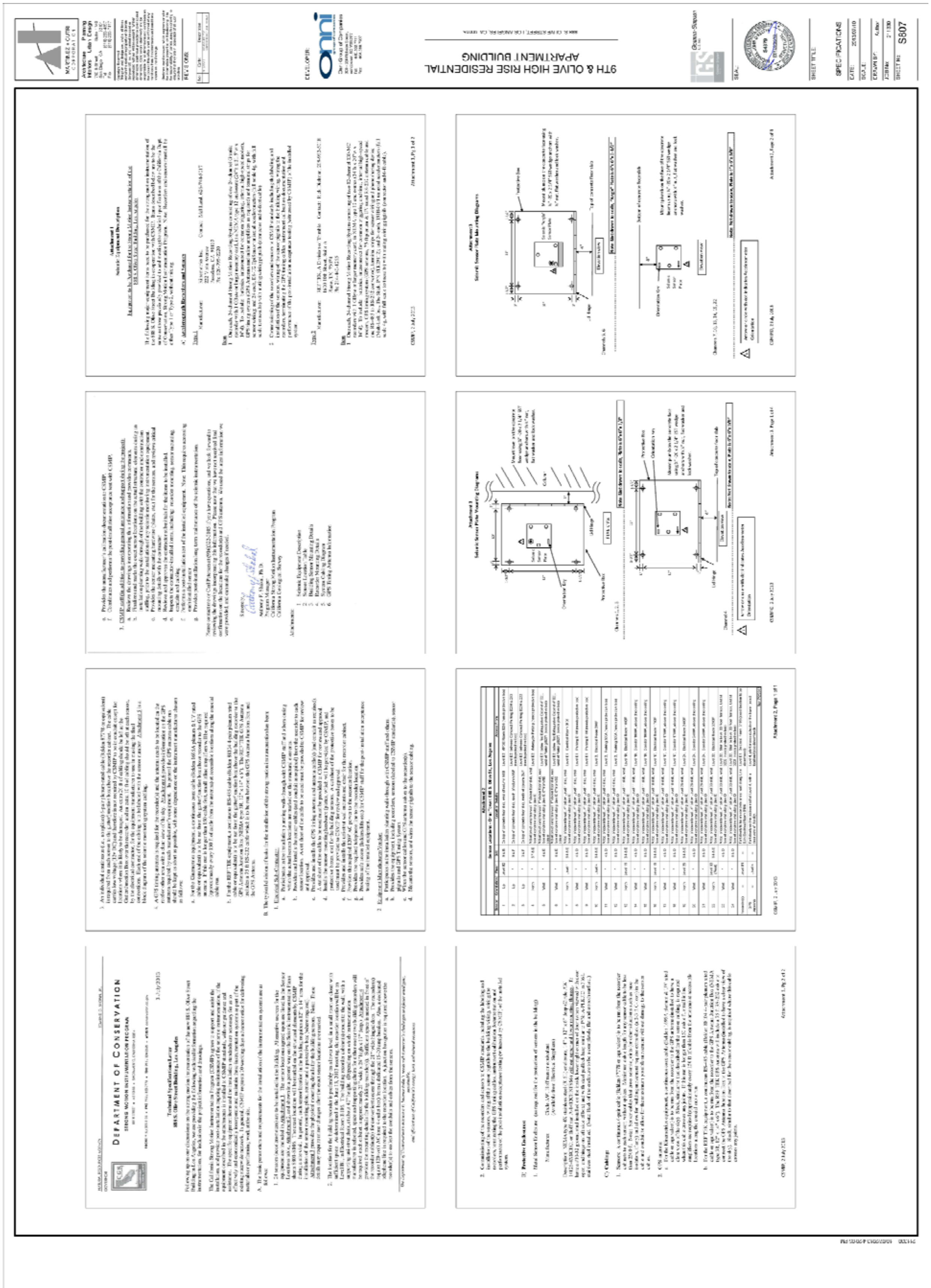
RECORDER(S)
PARKING
STORAGE
TRANSFORMER
GREASE INTERCEPTOR
HOUSE PUMP
TRASH & RECYCLE
ELEVATOR LOBBY
S802

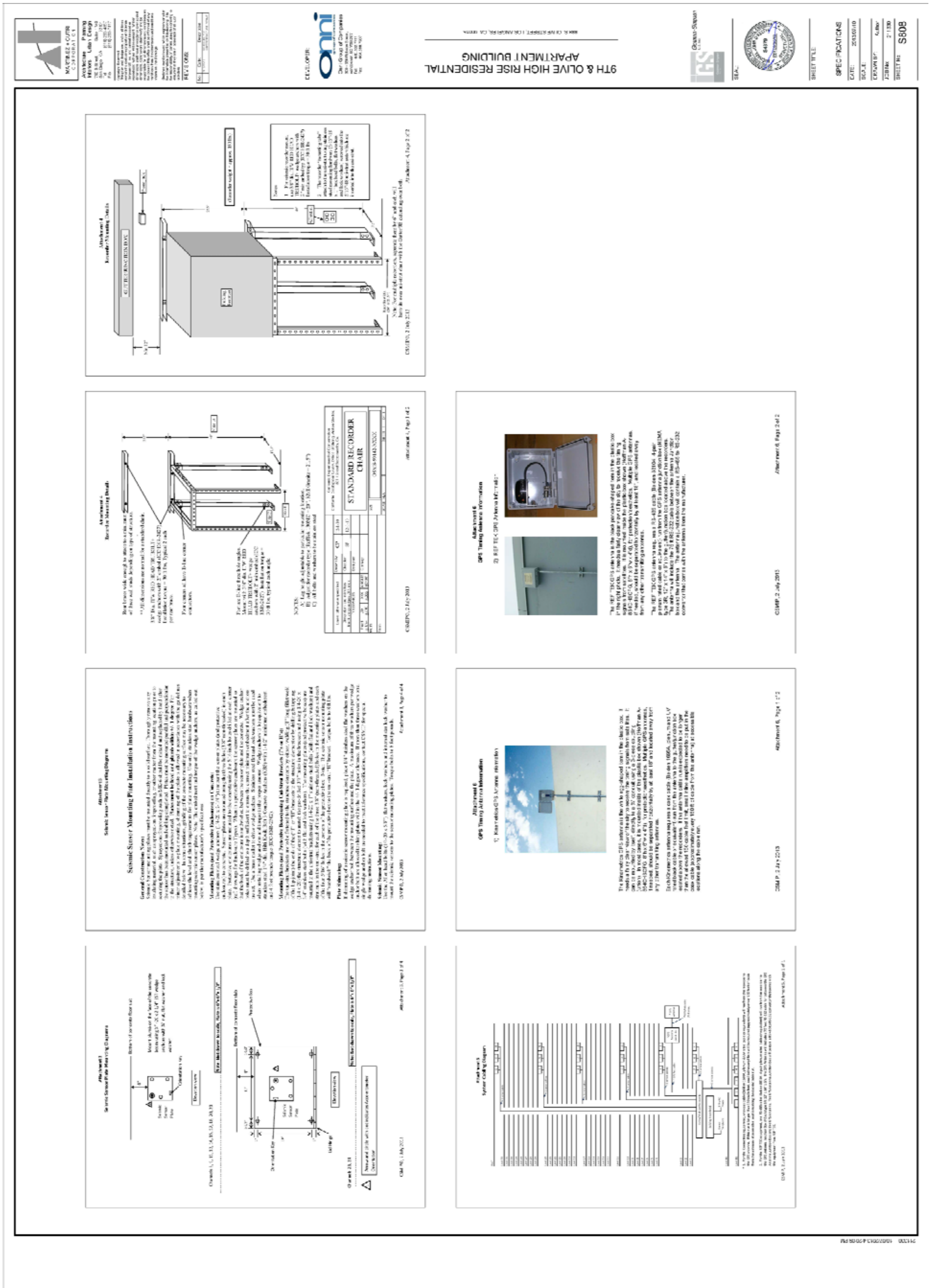

LEVEL 3 PLAN - SEISMIC SENSOR LAYOUT
GPS ANTENNA
MATCH LINE
ELEVATOR
PARKING
10
11
12
9TH & OLIVE HIGH RISE RESIDENTIAL
APARTMENT BUILDING
LEVEL 3 PLAN - SEISMIC SENSOR LAYOUT
S803


9TH & OLIVE HIGH RISE RESIDENTIAL
APARTMENT BUILDING
LEVEL 17 PLAN - SEISMIC SENSOR LAYOUT
LEVEL 10 PLAN - SEISMIC SENSOR LAYOUT
LEVEL 10 & 17 PLAN - SEISMIC SENSOR LAYOUT
S804
CORRIDOR
LOBBY
17
18
16
14
15
13


9TH & OLIVE HIGH RISE RESIDENTIAL
APARTMENT BUILDING
LEVEL 32 - SEISMIC SENSOR LAYOUT
LEVEL 24 PLAN - SEISMIC SENSOR LAYOUT
LEVEL 24 & ROOF PLAN - SEISMIC SENSOR LAYOUT
S805






9TH & OLIVE HIGH RISE RESIDENTIAL
APARTMENT BUILDING
SPECIFICATIONS
S808