Output feedback disturbance rejection control for building structure systems subject seismic excitations

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Abstract
In this paper, the output feedback disturbance rejection control (OFDRC) problem is considered for buildings structures subject seismic excitations. First, based on a mild assumption and a linear transformation, the addressed problem of building structure system is translated into the output feedback disturbance rejection control problem large-scale system with disturbances. Then, by utilizing generalized-proportional-integral-observer (GPIO) technique and output feedback domination approach, an output feedback decentralized disturbance rejection control law is derived via a systematic design manner. The multi-overlapping output feedback disturbance rejection controller is obtained according to the inverse transformation of a linear transformation. Strict theory analysis demonstrates that the states of the structure system will be stabilized to a small bounded region. Finally, an 8-story structure system is employed to evaluate the effectiveness of the proposed control strategy. Simulation results demonstrate that the proposed OFDRC exhibits better seismic loads attenuation ability and strong robustness against model uncertainties.

Keywords
Building structure, seismic excitation, generalized-proportional-integral observer, output feedback control, active disturbance rejection control

Introduction
Nowadays, more and more tall buildings are mushroomed in the city, which suffers from many natural hazards. Naturally, the protection of civil tall building structures and human occupants from natural excitations becomes one of the most imperative tasks.¹ To mitigate (or reduce) the undesirable effects of unknown natural excitations, the structural stability of the building structures could not be guaranteed only through improving the quality of architectural materials.² Therefore, the structural vibration control problem of tall building structures has been receiving more and more attentions from the field among civil, mechanical and control engineering.

Due to the significance of attenuating unknown natural excitations for building structure systems, much effort have been devoted to develop control schemes in the literature, such as linear quadratic regulator (LQR) theory,³ PD/PID control,⁴ H∞ control,⁵ sliding mode control.⁶ Since the tall building structure system usually has high dimensions, multiple inputs and outputs, and complex structure characters, how to design an effective controller for achieving the desired performance. In order to reduce the risk of the traditional centralized control methods on failure of control systems and enhance the reliability of control applications, some advanced control methods were proposed. By using the state information of the neighboring stories and LQR theory,⁶ proposed a multi-overlapping controller design method for tall building structures.⁷ considered the multi-overlapping decentralized static output feedback H∞ control approach for building structures by using linear matrix inequality
technique. An improved decentralized method for building structure systems was proposed in Ma and Yang based on sliding mode control strategy. In Ma and Yang, an adaptive feedback feedforward control approach was proposed to enhance the robustness of the building structures. It is should be pointed out that the aforementioned results are based on the assumption that the unknown natural excitations are regarded as disturbances. Except, the robustness of these control approaches are realized by attenuating the unknown disturbances rather than cancel them.

It is well known that disturbances and uncertain ties widely exist in practical engineering systems which bring adverse effects to control system. Many active disturbance rejection control (ADRC) techniques have been proposed, for example, and the references therein. The baseline of ADRC is that both the external disturbances and parameter uncertainties are summarized lumped disturbance during the design procedure. The ADRC controller is composed by two parts: nominal feedback control law and feedforward compensation part, where the nominal feedback control law is utilized for tracking/stabilization while the feedforward compensation part is used to improve the robustness against lumped disturbance. And ADRC methods have been successfully implemented in PMSM system, piezoelectric system, air-fuel ration control systems, and robotic systems, etc. The ADRC idea has been reported in Ma and Yang for the building structure systems. However, the result is based on the full information of the whole systems are measurable. proposed decentralized output feedback control method based on sliding mode control technique. Due to the appearance of signum function, the proposed controller is discontinuous which may bring adverse effects to the control systems. To the best of our knowledge, there are few results on the output feedback disturbance rejection control (OFDRC) problem of building structure systems in the literature.

In this paper, we will investigate the OFDRC problem for buildings structures subject seismic excitations. To this end, the building structure system subject seismic events is translated into a large-scale interconnected system with disturbances via a linear transformation. And the considered OFDRC problem of building structure systems is converted into the decentralized OFDRC problem of the large-scale interconnected systems. Then, by using high gain scaling transformation, the generalized-proportional-integral observer (GPIO) technique and output feedback domination approach, decentralized OFDRC laws are derived based on the output information of every subsystems. The decentralized OFDRC laws are composed by an output feedback control (OFC) and feedforward compensate term which is generated by GPIO. Strict theory analysis demonstrates that under the proposed decentralized OFDRC laws the states of the whole large-scale interconnected system will be stabilized to an arbitrarily small domain. Through the inverse transformation of the aforementioned linear transformation, the multi-overlap ping output feedback disturbance rejection controllers are obtained eventually. Compared to the aforementioned control strategies for building structure systems, the major contribution of this paper could be summarized as follows: (i) Only the displacement information is needed to during the design process; (ii) The seismic excitations is cancelled rather than attenuated, thus the current OFDRC could offer remarkable disturbance rejection ability; (iii) The current OFDRC has a simple linear structure which is beneficial to practical applications.

The paper is organized as follows. In the next Section, the mathematical model of building structure systems is introduced. The main result is given in Section 3. Simulation is carried out in Section 4 to illustrate the validity of the proposed control approach. Finally, some closing remarks are included in Section 5.

### The mathematical model of building structure systems

The \( n \)-degree-of-freedom building structure system with unknown external excitations could be described by the following model

\[
Mp(t) + Cp(t) + Kp(t) = Tu(t) - M \dot{x}_g(t)
\]

where \( p(t) = [p_1(t), \ldots, p_n(t)]^T \in \mathbb{R}^n \) denotes the displacement vector, and \( u(t) = [u_1(t), \ldots, u_n(t)]^T \in \mathbb{R}^n \) denotes control force. \( \dot{x}_g(t) \) denotes unknown external excitation, \( \alpha = [1, \ldots, 1]^T \in \mathbb{R}^n \) is a unit column vector. \( M, C, K \) and \( Tu \in \mathbb{R}^{n \times n} \) denote the mass, damping, stiffness and control location matrices, respectively, which could be defined by

\[
T_u = \begin{bmatrix} 1 & -1 & \cdots & -1 \\ 1 & \cdots & \cdots & 1 \\ \cdots & \cdots & \cdots & \cdots \\ 1 & \cdots & \cdots & 1 \end{bmatrix}
\]

\[
C = \begin{bmatrix} c_1 + c_2 & -c_2 \\ -c_2 & c_2 + c_3 \\ \vdots & \vdots \\ -c_{n-1} & c_{n-1} + c_n & -c_n \\ -c_n & c_n & \cdots & \cdots & \cdots & \cdots & -c_n & c_n \end{bmatrix}
\]

\[
K = \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 + k_3 & -k_3 \\ \vdots & \vdots & \vdots & \vdots \\ -k_{n-1} & k_{n-1} + k_n & -k_n \\ -k_n & k_n & \cdots & \cdots & \cdots & \cdots & -k_n & k_n \end{bmatrix}
\]

If \( c_i \) that the values of the story damping coefficients are known, the damping matrix \( C \) which has the same
structure as $K$ in the equation above could be obtained by replacing $k_i$ by $c_i$.

Assume only $p_i, i = 1, \ldots, n$ is measured in building structure systems (1). The objective of this paper is to design an OFDRC for system (1) such that the building structure system has strong robustness against unknown seismic excitations.

Consider the following linear transformation

$$x_{i1} = p_i, x_{i2} = \hat{p}_i, i = 1, \ldots, n.$$ (5)

Then system (1) is decomposed into $n$ subsystems

$$\dot{x}_{i1} = x_{i2},$$
$$\dot{x}_{i2} = f_i(x) + v_i + d_i, i = 1, \ldots, n,$$ (6)

with

$$y_j = \frac{u_j - u_j + 1}{m_j}, j = 1, \ldots, n - 1, v_n = \frac{u_n}{m_n}$$ (7)

and

$$f_i(x) = \frac{1}{m_i}[-(k_1 + k_2)x_{i1} + k_2x_{i2} - (c_1 + c_2)x_{i2} + c_2x_{i2}],$$
$$f_i(x) = \frac{1}{m_i}[-(k_1 + k_2)x_{i1} + k_2x_{i2} - (c_1 + c_2)x_{i2} + c_2x_{i2}],$$
$$f_i(x) = \frac{1}{m_i}[-(k_1 + k_2)x_{i1} + k_2x_{i2} - (c_1 + c_2)x_{i2} + c_2x_{i2}],$$

which will be used for the main result of the paper.

Thus far, the OFDRC problem for system (1) is translated into the decentralized OFDRC problem of large-scale interconnected system (6).

**Main results**

In this section, we will concentrate on the designing of the decentralized OFDRC problem of large-scale interconnected system (6), which mainly could be divided into steps.

**GPIO observer design**

For system (6), only when the output information (i.e. the position information $y_j$) could be utilised. It is necessary to estimate the unmeasured state $x_{i2}$ and the unknown external excitation $d_i$. For this purpose, the GPIO technique will be employed to design observer for system (6) such that both the unmeasured state and unknown external excitation could be recovered.

**Assumption 3.1.** The disturbance $d_i(t)$ meets the following two conditions:

(i) $d_i(t) \in C^q$;

(ii) There exists a constant $\theta_i$ such that $|d_i^q| = |\gamma_i^q| \leq \theta_i$.

**Remark 3.1.** Choosing reasonable seismic wave is the premise of time history analysis of seismic response for engineering structure systems. However, the number of measured seismic waves is limited, and it is closely related to the site conditions of the places. In Thenozi S and Yu, it is pointed out that it is not easy to obtain the seismic signals with simple integration since most of the existing controllers are based on the systems’ states. For the study of seismic events, much efforts have been paid to the synthesize artificial seismic, such as, trigonometric series method and synthesized acceleration time series technique. In Assumption 3.1, the seismic excitation is seen as external disturbance for building structure systems, which could be used to depict many kinds of disturbances such as harmonic disturbance, constant disturbance, ramp disturbance, polynomial disturbance, and so on.

Let $x_{i2}(t) = d_i, x_{i4}(t) = \hat{d}_i, \ldots, x_{i,q+1}(t) = d_i^q = \gamma_i^q$. Then system (6) can be rewritten as

$$\begin{align*}
\dot{x}_{i1} & = x_{i2}, \\
\dot{x}_{i2} & = f_i(x) + v_i + x_{i3}, \\
\dot{x}_{i3} & = x_{i4}, \\
\vdots & \quad i = 1, \ldots, n \\
\dot{x}_{i,q+1} & = \gamma_i^q \\
y_i & = x_i + 1
\end{align*}$$ (9)

Thus far, the estimation problem of the unmeasured state $x_{i2}$ and the unknown external excitation $d_i$ is converted into the states estimation problem for system (9). For this purpose, a high-gain observer is designed for system (9), which could be depicted by

$$\begin{align*}
\dot{\hat{x}}_{i1} & = \hat{x}_{i2} + L\hat{x}_{i}(x_{i1} - \hat{x}_{i1}), \\
\dot{\hat{x}}_{i2} & = v_i + \hat{x}_{i2} + L^i\hat{a}_i(x_{i1} - \hat{x}_{i1}), \\
\dot{\hat{x}}_{i3} & = \hat{x}_{i4} + L^i\hat{a}_i(x_{i1} - \hat{x}_{i1}), \\
\vdots & \quad i = 1, \ldots, n \\
\dot{\hat{x}}_{i,q+1} & = \hat{x}_{i,q+1} + L^i\hat{a}_i(x_{i1} - \hat{x}_{i1}).
\end{align*}$$ (10)

where $L \geq 1$ is a gain parameter to be determined, and $a_1, \ldots, a_{i,q+1}$ are chosen such that
\[ A_i = \begin{bmatrix}
-a_{i1} & 1 & 0 & \cdots & 0 \\
-a_{i2} & 0 & 1 & \cdots & 0 \\
& \vdots & \vdots & \ddots & \vdots \\
-a_{i,n} & 0 & 0 & \cdots & 0 \\
-a_{i,n+1} & 0 & 0 & \cdots & 0 
\end{bmatrix} \] (11)

is a Hurwitz matrix.

Define the state error as
\[ e_j = x_j - \dot{x}_j, i = 1, \ldots, n, j = 1, \ldots, q + 1, \]
then combining (9) with (10), it is not difficult to obtain the observer error system
\[ \dot{e}_i = L_i \dot{A}_i e_i + F_i(x, d_i), i = 1, \ldots, n \] (12)
where \( e_i = [e_{i1}, \ldots, e_{i,q+1}]^T \), and
\[ F_i(x, d_i) = \begin{bmatrix}
0, & f_i(x) / L, & 0, & \cdots, & \gamma_i / L^5
\end{bmatrix}^T. \]

**Decentralized output feedback disturbance rejection controller design**

For system (9), if we introduce the following coordinate transformation
\[ z_j = x_j / L, \dot{z}_j = \dot{x}_j / L, j = 1, \ldots, q + 1, v_i = \nu_i / L^2 \] (13)
then according to the first two subsystem of system (9) we have
\[ \dot{z}_i = L_i \dot{A}_i z_i + L_i \dot{B}_i (v_i + z_d) + \tilde{f}_i(x), i = 1, \ldots, n \] (14)
with
\[ z_i = \begin{bmatrix}
z_{i1} \\
z_{i2}
\end{bmatrix}, A_i = \begin{bmatrix}
0 & 1 & 0 & \cdots & 0 \\
0 & 0 & 1 & \cdots & 0 
\end{bmatrix}, B_i = \begin{bmatrix}
0 \\
1
\end{bmatrix}, \text{and } \tilde{f}_i(x) = \begin{bmatrix}
0 \\
\tilde{f}_i(x) / L^2
\end{bmatrix}^T. \]

Under the GPIO (10) and the coordinate transformation (13), for system (6), we could design the following decentralized output feedback disturbance rejection controller
\[ v_i = L^2 v_i = -L^2 (K_{0i} z_i + z_d), i = 1, \ldots, n \] (15)
where \( K_{0i} = [k_{i1}, k_{i2}]^T \) with \( k_{i1}, k_{i2} > 0 \) such that the matrix
\[ \begin{bmatrix}
0 & 1 \\
-k_{i1} & -k_{i2}
\end{bmatrix} \] (16)
is Hurwitz.

Combine system (12), (14) and (15), the closed-loop system can be written as
\[ \dot{\eta}_i = L A_i \eta_i + F_i(x, d_i), i = 1, \ldots, n \] (17)
where \( \eta_i = [z_i^T, e_i^T]^T, F_i(x, d_i) = [\tilde{f}_i(x), \tilde{f}_i^2(x, d_i)]^T, \)
and \( A_i = \begin{bmatrix}
A_i - B_i K_{0i} & B_i K_i \\
0 & A_i
\end{bmatrix} \) with \( K_i = [K_{0i}^T, I]^T. \)

Since both \( A_i - B_i K_{0i} \) and \( A_i \) are Hurwitz matrices, it is easy to show that there exists a positive definite matrix \( P_i \) which can satisfy that
\[ A_i^T P_i + P_i A_i = -I \] (18)

According to the analysis above, we can obtain the following theorem.

**Theorem 3.1.** Consider system (6), if Assumption 3.1 holds, the states of the whole closed-loop system (6) are will converge to the following bounded region
\[ V(\eta) = -L ||\eta||^2 + 2\eta^T P_i F_i(x, d_i), i = 1, \ldots, n \] (20)

Based on the equation (8), it can be shown that
\[ \tilde{f}_i(x) \leq c_0 L \|z_i-1,1\| + |z_i,1| + |z_i,1,1| + |Lz_i-1,1| + |Lz_i-1,2| + |Lz_i+1,2| \]
\[ \leq c_0 \|\eta_{i-1,1}\| + \|\eta_{i,1}\| + \|\eta_{i,1,1}\| + \|L\eta_{i-1,1}\| + \|L\eta_{i,1,1}\| \]
\[ \leq c_0 \|\eta_i\|, i = 2, \ldots, n - 1 \] (21)

Where \( \eta = [\eta_1^T, \ldots, \eta_n^T]^T. \) Similarly, it is easy to show that
\[ \tilde{f}_i^2(x) \leq c_0 \|\eta\|, \tilde{f}_i^2(x) \leq c_0 \|\eta\| \] (22)

By Assumption 3.1, it is not difficult to verify that
\[ \frac{\gamma_i^{(o)}}{L^2} \leq \frac{\theta_i}{L^2} \] (23)

Based on the inequalities (21) and (23), for \( i = 1, \ldots, n \) it is easy to show that there is positive scalar \( \rho \) such that
\[ \|2\eta_i^T P_i F_i(x, d_i)\| \leq 4\|\eta_i^T P_i \tilde{f}_i(x, d_i)\| + 2\|\eta_i^T P_i \tilde{f}_i(x, d_i)\| \]
\[ \leq 4c_0 \lambda_{\max}(P_i) \|\eta\|^2 + 2\theta_i \lambda_{\max}(P_i) \|\eta\| \]
\[ \leq (4c_0 + 1) \lambda_{\max}(P_i) \|\eta\|^2 + \lambda_{\max}(P_i) \theta_i^2 \] (24)
For the whole system (6), we choose Lyapunov function $V(\eta) = \sum_{k=1}^{n} V_k(\eta_k)$. It could be derived that
\[ nP_M ||\eta||^2 \leq V(\eta) \leq nP_M ||\eta||^2 \] 
(25)

By using inequalities (20)–(25), taking the derivative of $V(\eta)$ along the system (6) yields
\[ \dot{V}(\eta) \leq -L \sum_{i=1}^{n} ||\eta||^2 + \sum_{i=1}^{n} 2m_i^2 P_i f_i(x_i, d_i) \]
\[ \leq -L \sum_{k=1}^{n} ||\eta||^2 + (4c_0 + 1) \sum_{k=1}^{n} \lambda_{\max}(P_k)||\eta||^2 \]
\[ + \sum_{k=1}^{n} \lambda_{\max}(P_k) \theta_i^2 \]
\[ = \left[ L - (4c_0 + 1) \sum_{k=1}^{n} \lambda_{\max}(P_k) \right] \frac{V(\eta)}{nP_M} \]
\[ + \sum_{k=1}^{n} \lambda_{\max}(P_k) \theta_i^2 \]
\[ \leq \left[ L \frac{nP_M}{nP_M} - (4c_0 + 1) \right] V(\eta) + nP_M \theta^2 \]
(26)

By choosing
\[ L \geq \max\{nP_M(4c_0 + 1), 1\}, \]
(27)

it follows from (26) that
\[ V(\eta) \leq \frac{n^2 P_M^2 \theta^2}{L - nP_M(4c_0 + 1)} \left[ V(0) - \frac{n^2 P_M^2 \theta^2}{L - nP_M(4c_0 + 1)} \right] \]
\[ \times e^{-\left(\frac{nP_M}{L - nP_M(4c_0 + 1)}\right)t} \]
(28)

It can be concluded from (25) that all the states of the closed-loop system (6) will be globally stabilized to the bounded region $\Omega$.

It is obviously from (24) that if $\theta \to 0$ as $t \to \infty$, then under the proposed decentralized output-feedback control controller (14), all the states of system (1) will exponentially converge to the origin.

Remark 3.2: It is should be pointed out that the OFDRC proposed (15) is composed by two parts. The first part is baseline output feedback control law
\[ u_i = L^2 v_i = -L^2 (K_{i\beta} \hat{z}_i), i = 1, \ldots, n, \]
(29)

and the second part is $\hat{z}_{\beta}$ which is used to compensate the disturbance. If we do not consider the influence of the disturbance, then according to (7), (10) and (29), the state output feedback controller (OFC) is derived
\[ u_i = \sum_{k=1}^{n} -m_i L^2 \left( k_{i\beta} \hat{x}_i + \frac{k_2}{L} \hat{x}_2 \right) \]
(30)

with the state observer
\[ \hat{x}_1 = x_{12} + L a_1 (x_{11} - x_{1i}), \]
\[ \hat{x}_2 = v_i + L^2 a_2 (x_{11} - x_{1i}), i = 1, \ldots, n \]
(31)

where $a_1$ and $a_2$ are the coefficient of Hurwitz polynomial $p(s) = s^2 + a_2 s + a_1$. It seems that the controller (30) is much simpler than the controller (32). However, compare to the controller (32), the controller (30) provides stronger robustness against disturbance and parameter uncertainties, which could be illustrated by simulations in the next part.

Remark 3.3. Based on output feedback domination approach and GPIO technique, the OFDRC (15) is proposed in this paper. By utilising (7), (10) and (15), the explicit form of the OFDRC is obtained
\[ u_i = \sum_{j=1}^{n} m_j v_j \]
\[ = \sum_{j=1}^{n} -m_j L^2 (K_{j\beta} \hat{z}_j + \hat{z}_{\beta}) \]
(32)
\[ = \sum_{j=1}^{n} -m_j L^2 (k_{j\beta} \hat{x}_j + k_2 \hat{x}_2 + \hat{z}_{\beta}) \]
\[ = \sum_{j=1}^{n} -m_j L^2 \left( k_{j\beta} \hat{x}_j + \frac{k_2}{L} \hat{x}_2 + \hat{z}_{\beta} \right) \]

with $i = 1, \ldots, n$. Obviously, the controller (30) has simple linear structure. Once the Hurwitz matrix (16) and (11) are chosen, we only need to regulate the scaling gain $L$, which is used to handle the interconnected terms $f_i(x_i), i = 1, \ldots, n$. Therefore, the provided linear OFDRC is beneficial to the practical applications.

Simulation

To verify the effectiveness of the proposed output feedback disturbance rejection control approach. We will employ an 8-story shear beam model proposed in Ma et al. for the study.

The parameters for the building structure system are also borrowed from: $m_i = 3.456 \times 10^5 \text{kg}, c_i = 2.4 \times 10^6 \text{N} \cdot \text{s} / \text{m}$, and $k_i = 3.404 \times 10^8 \text{N} / \text{m}$. It is assumed that the building structure system suffered from the following seismic excitation
\[ d(t) = \tilde{x}_x = \frac{3}{4} (\sin(15t) + \cos(20t)) f(t) \]
(33)

with
The seismic excitation rejection ability

To evaluate the efficiency of the proposed (32), the OFC (30) and uncontrolled methods will be employed in the simulation for comparison. For fair comparison, both the OFDRC (32) and the OFC (30) use the same controller bandwidth and Observer bandwidth, but the OFC (30) has relative larger scaling gain $L$, which are shown in Table 1.

The time responses of the displacements and the absolute maximum interstory drift of each floor are shown in Figure 1 (solid blue line). Figure 2 (solid blue line).whose dynamic response characteristic is shown in Figure 3 (solid blue line).

\[ f(t) = \begin{cases} \frac{t^2}{2} & t \in [0, 3] \\ 1 & t \in (3, 8] \\ e^{-0.25(t-8)} & t \in (8, 25] \\ 0 & t \in (25, +\infty) \end{cases} \]

**The seismic excitation rejection ability**

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provided in Figures 1 to 2. Clearly, compared with the OFC (30) and the uncontrolled scenario, under the proposed OFDRC (32) the responses of displacement and the absolute maximum interstory drift are significantly reduced. This is because that the influence of seismic excitation could be effectively estimated (Figure 3) and is cancelled by the OFDRC (32). While the maximum control forces of the OFDRC (32) and the OFC (30) are given in Figure 4, it is observed that the maximum control forces of the OFC (30) are smaller than that of OFDRC (32). Therefore, it could be concluded that the proposed OFDRC method exhibits good performance when the building structure system suffers such seismic events.

### Table 2. The change rate of system parameters.

| damping | changes | stiffness | changes |
|---------|---------|-----------|---------|
| $c_1$, $c_3$, $c_5$, $c_7$ | $-5\%$ | $k_1$, $k_3$, $k_5$, $k_7$ | $10\%$ |
| $c_2$, $c_4$, $c_6$, $c_8$ | $10\%$ | $k_2$, $k_4$, $k_6$, $k_8$ | $-5\%$ |

To assess the robustness of proposed method with regard to the uncertainties will be taken into consideration.

Assume the nominal values of the mass, damping and stiffness parameters are $m_0 = 3.456 \times 10^3$ kg, $c_0 = 2.4 \times 10^6$ N m s$^{-1}$, and $k_0 = 3.404 \times 10^9$ N m, $i = 1, \ldots, 8$, respectively, and the unknown seismic excitation is given in (33). Here, it is supposed that the mass of each story does not change, and the damping $c_i = (1 + \Delta c_i)c_0$ and stiffness $k_i = (1 + \Delta k_i)k_0$ with uncertainties $\Delta c_i, \Delta k_i$, $i = 1, \ldots, 8$ within 10%.

For simulation studies, the specific values of damping and stiffness uncertainties is shown in Table 2. We choose the same control parameters for OFDRC (32) as in Table 1. The simulation results are given through Figures 5 to 6.

It is observed from Figure 5 that the maximum story displacement drift (relative to the ground) of each story is no more than 0.03 cm, which verifies that the proposed OFDRC method have not only disturbance rejection ability, but also good robustness to parameter uncertainties.

### Conclusion

An OFDRC strategy has been proposed for building structure systems subject seismic excitations via GPIO.
and output feedback domination techniques. Under the proposed OFDRC approach, the seismic excitations (disturbances) is cancelled by estimations of GPIO, and the (uncertain) interconnected terms are dominated rather than attenuated.\textsuperscript{5,21} Compared to the decentralized sliding mode part OFC method, the proposed OFDRC has a simple linear structure which is beneficial to practical applications. The simulation results have illustrated that the proposed OFDRC has strong robustness against seismic excitations and uncertainties.

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